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HELMET-MOUNTED SIGHT/DISPLAY APPLICATIONS

VOL. IV, BASELINE HMS/D SYSTEM

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Honeywell Inc.
Systems and Research Division

TECHNICAL REPORT AFFDL-TR-69-118, VOL. IV

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FOREWORD

The work reported in this document was performed by Honeywell Inc. Systems and Research Division, 2700 Ridgway Road, Minneapolis, Minnesota, 55413. Work was performed during the period November 1968 to May 1969 both under the auspices of Honeywell Inc. and under Air Force contract F33615-69-C-1176. The Air Force program Monitor was Mr. E. M. Bobbett/ FDCR.

In addition to the listed authors, significant contributions to the writing of this report were made by Darrel R. Blackburn, David A. Church, Wallace E. Helmbrecht, and Ronald F. Meuser, all employees of Honeywell Inc., Systems and Research Division.

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This technical report has been reviewed and approved.

Loren A. Anderson, Lt. Colonel, USAF
Chief, Control Systems Research Branch
Flight Control Division

ABSTRACT

This report describes the system studies and experimental work done to determine the applicability of a helmet-mounted sight/display (HMS/D) to high-performance aircraft of the F-15 type. The HMS/D was found to have several areas of applicability to such aircraft, particularly in the mission phases having to do with weapon delivery. Closed-loop performance of the sight/display combination was examined experimentally as a part of the study. The performance experiment is based on the ability of the engineer subjects to sight and track targets displayed on the helmet display. Interface of the HMS/D with other aircraft systems was considered, and a baseline HMS/D system was defined to the degree necessary to enter a prototype development phase.

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SECTION I

INTRODUCTION

This volume describes the conceptual and analytical work leading to the description of a baseline HMS/D system applicable to the F-15 aircraft. The work is an extension of that reported in Volumes II and III of this report and covers the equipment-oriented aspects of the problem. The work reported on in this volume was performed in response to Tasks 7 and 8 and to a portion of Task 6 of Honeywell Inc. Proposal 8B-N-4, dated 22 July 1968. This volume also responds to the following requirements of Exhibit A of contract F33615-69-C-1176:

- Analyze the feasibility of performing the weapon delivery missions (3. 1).
- Determine what combinations are best suited for what phases (3. 3).
- Establish the relationship between the HMS/D and associated systems (3. 3. 1) and (3. 7).
- Determine the design feasibility and the manufacturing practicality of the HMS/D (3. 9).

The baseline system described in this volume is meant to serve in two capacities:

- It may be used by the Air Force as the basis for discussions concerning the needs of the service and for choosing those features of the HMS/D which will be of greatest assistance in meeting established needs.
- It may be used by a contractor as the starting point for a program of prototype design and development leading to a workable and flyable HMS/D for test and evaluation purposes.

Potential implementations of the HMS/D range from the very simple to the very complex. A basic helmet sight with the addition of one or two simple display elements presenting discrete bits of information marks one end of the spectrum of complexity. The other end encompasses complex systems in which the helmet sight is used both for sighting tasks external to the aircraft and for aircraft management control functions within the cockpit while the helmet display presents a multiplicity of scene and symbolic images simultaneously and in sequence. The lower end of this spectrum is clearly within the state of the art today. The upper end is beyond today's capability. The present spectrum is broad, however, and does include a wide variety of both sight and display functions. One of the major decisions which must be made before proceeding with the development of a prototype is the choice from the available capabilities of the HMS/D of those which should be implemented in the first flyable device.

SECTION II

SYSTEM CONCEPT ANALYSIS

Concepts were formulated and developed for each of the potential applications of the HMS/D to weapon delivery tasks and to other tasks representative of the ability of the HMS/D. These included:

- Air-to-air combat
  - (1) Long-range target identification (including radar acquisition)
  - (2) Missile firing - passive electro-optical homing missiles
  - (3) Missile firing - semi-active radar homing missiles
  - (4) Fixed gun firing
- Air-to-ground combat
  - (1) Target acquisition and identification
  - (2) Target location (including navigation update)
  - (3) Missile firing
  - (4) Fixed gun firing
  - (5) Bombing

In general, the concepts were evaluated by developing the following descriptions:

- General concept (including block diagram showing functional relationships)
- Operational procedure using concept
- Equipment used
- Information needed on display
- Controls needed
- Computation needed
- Impact of HMS/D design parameters on performance
- Advantages and disadvantages

AIR-TO-AIR COMBAT APPLICATIONS

Air-to-air combat applications considered were: (1) long-range radar acquisition and optical target identification; (2) missile firing involving both passive electro-optical (E-O) homing missiles and semi-active radar homing missiles; and (3) fixed gun firing.

Long-Range Radar Acquisition and Optical Target Identification

General Concept -- The probable approach to this application is the combination of a telescopic electro-optical tracker with radar and the HMS/D. This arrangement will allow one man to operate a type of system which, in two-man applications, has a demonstrated capability to meet mission performance requirements. A block diagram of the system is shown in Figure 1.

Operational Procedure -- The mode of operation is as follows:

- Radar imagery is displayed on the HMS/D.
- Pilot locks the radar to the target by placing range and azimuth gate symbols over the displayed target return and pressing lock-on button.
- Electro-optical TV tracker is slaved to the helmet sight. Radar pointing direction in azimuth and elevation is displayed on the HMS/D along with the E-O tracker video output.
- Pilot moves his head to bring the radar cue to the center of the screen.
- Pilot sees a magnified image of the target and stabilizes it with his head motion. Pilot identifies the target.
- Pilot locks the E-O tracker to the target if he so desires.
- Optionally, pilot sights on the distant target directly and uses the identification device to obtain magnification of the image.

Radar search and acquisition before use of the identification device at extreme range is desirable since, at very long ranges, targets will not be visible to the unaided eye, and direct search with the high-magnification telescope will be difficult. With the radar locked, the identification telescope is directed to the target by cues on the helmet display.

Information Displayed - Radar Acquisition -- The same information normally displayed on the radar scope is required on the helmet display during long-range radar search and acquisition. A typical display is shown in Figure 2.

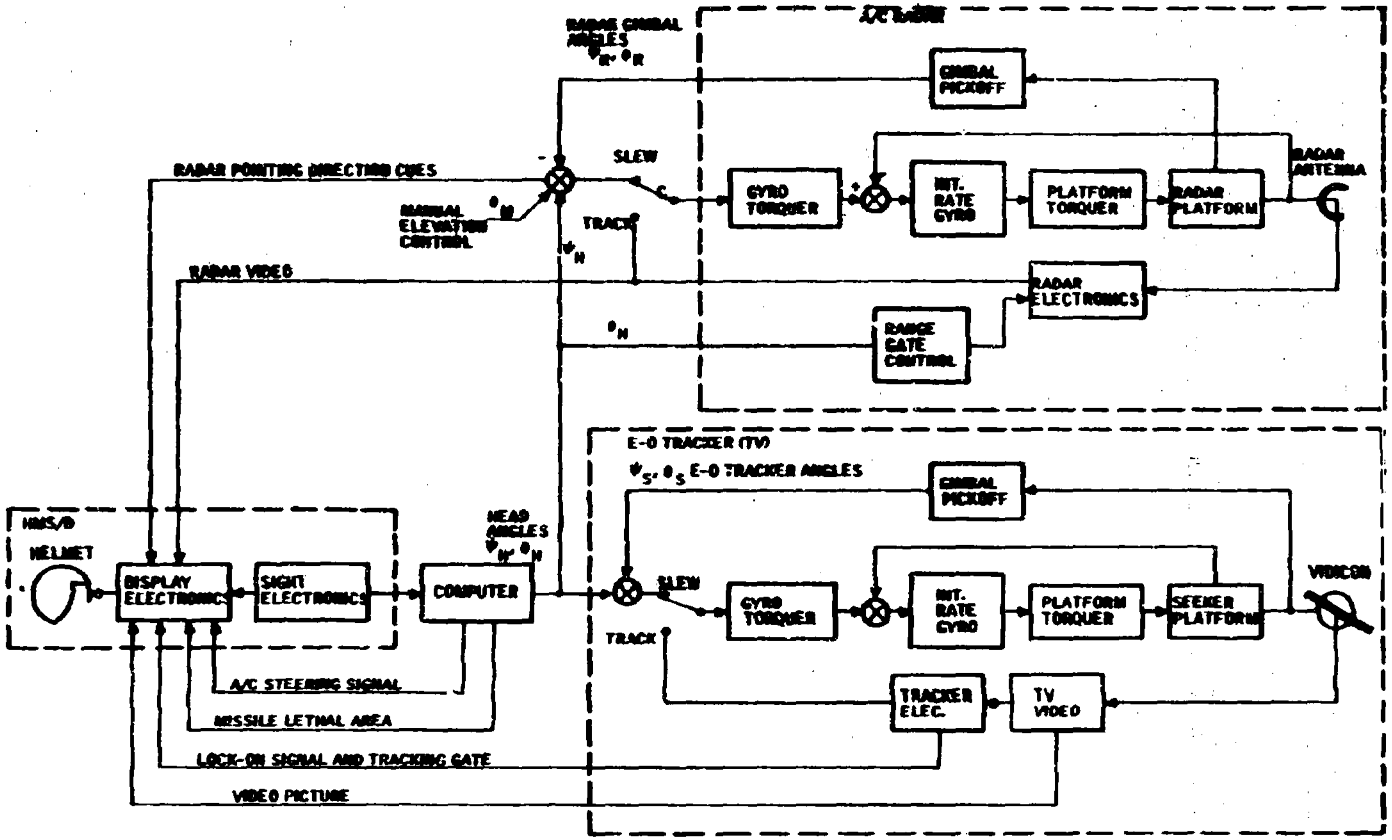


Figure 1. Long-Range Identification System Concept

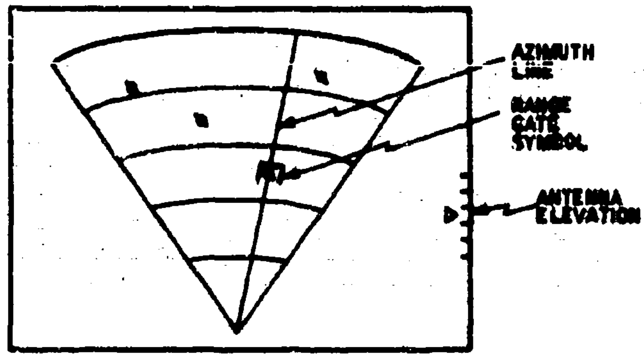


Figure 2. Typical Radar Acquisition Display

Returns from potential targets are shown in azimuth and range coordinates, and antenna elevation is shown by a marker at the edge of the display. The azimuth line and range gate are placed over the desired target to lock the radar. The azimuth line is positioned by the azimuth motion of the helmet sight, and the range gate is positioned by helmet sight elevation. Antenna elevation is controlled by a manual adjustment separate from the HMS/D. The decision to have the HMS/D control the azimuth and range rather than azimuth and elevation was based on the comments of radar operators and pilots that the elevation adjustment will be most effective if it is free from momentary changes caused by vibration of the pilot's head. The pilot will also be subject to less constraint on his motion if he is not required to maintain a specific head elevation to get a good radar plot.

Controls - Radar Acquisition -- In addition to the helmet sight, two controls are required for radar acquisition:

- HMS/D Mode Control (two modes required)

  Search - The azimuth-versus-range plot is presented. Antenna elevation is adjusted manually. The helmet sight has no control function.

  Acquisition - The azimuth line and range gate are presented. Antenna elevation is adjusted manually. Antenna azimuth and gate position are adjusted by the helmet sight.

- Acquisition Control - After the gate is positioned over the target, the operation of the acquisition control locks the radar to the target and breaks the control links from the helmet sight and elevation control.

HMS/D Design Factors - Radar Acquisition -- The display of the radar plot and acquisition symbols need not be in true relation to the outside world. A display which subtends the same angle as the present radar scope when viewed from the pilot's normal position should be sufficient for a readable display; in fact, it may be "too large". The amount of motion by the pilot's head required to position the antenna and the range gate may be set at any desired ratio of head-to-symbol motion. The value chosen will depend on the display size chosen, and the accuracy with which the head can be positioned and should be established by experimentation. Resolution of the radar display will be considerably coarser than that for more detailed imagery and therefore will not define a limiting requirement on the helmet display capability.

Information Displayed - Identification -- The primary information required for long-range identification of a target is the magnified image of the target. To assist in aligning the identification device to the target, cues showing the direction to the target as determined by the radar are desirable. If the identification device uses a gate size smaller than its overall field of view, the gate outline should also be shown. One possibility for such a display is shown in Figure 3.

In Figure 3(a), the tracker gate is seen but no target is in the field of view and therefore no image appears. The cueing arrow points the direction to the radar line to the selected target. In Figure 3(b), the cueing symbol shows that the line to the target is within the field of the display but, due to errors in the system or differences between display and sensor field sizes, the image is still off screen. A visual search around the radar cue should bring the image into view. In Figure 3(c), such a search has been performed, and the target image is seen. The radar cue has been brought to the center of the screen, and, to avoid confusion of images at the tracker gate, the symbol has been blanked out by the display system. Identification may be accomplished at this point, if possible, or the image may be brought into the tracker gate and the tracker brought to lock to give a more stable view of the target. When the identification device is used without the radar being locked, the display is the same except that no cue symbols appear.

When the identification device is used without obtaining radar lock, the enemy craft is sighted in the real world, and the sensor is pointed at it by using the tracker gate symbol as a sight reticle. With the gate either on or scanned around the target, the magnified image will be obtained. Identification and tracker lock are then carried out as described above.

Controls - Identification -- The following controls are used during long-range target identification:

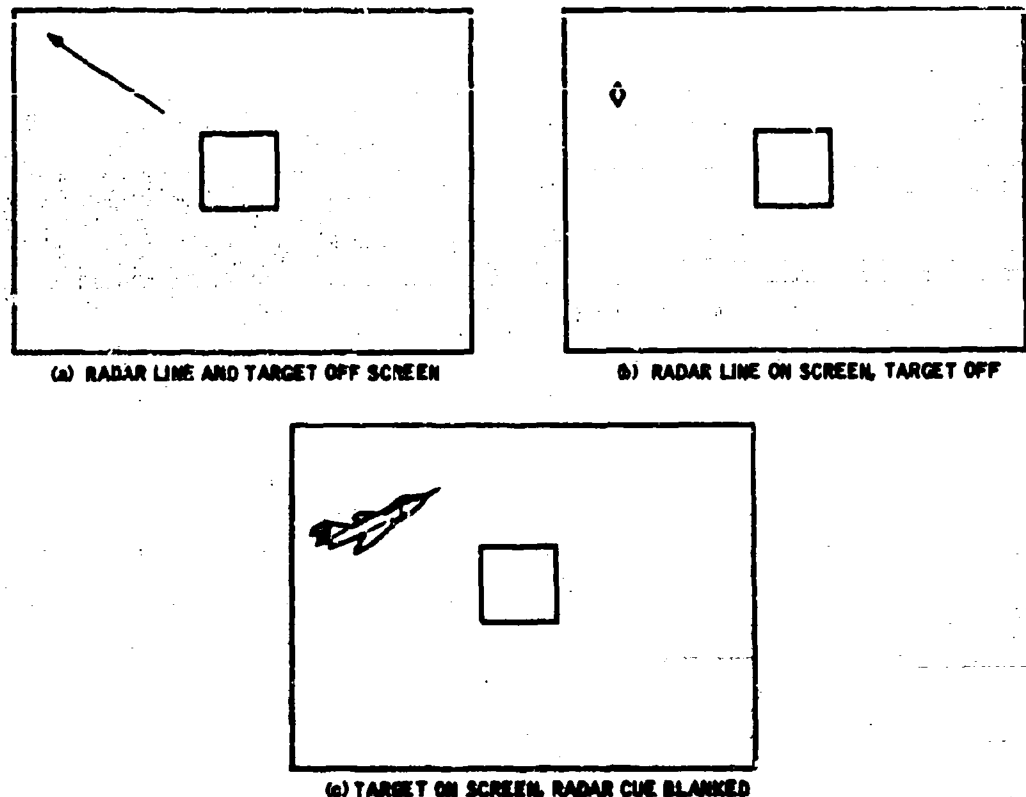


Figure 3. Typical Long-Range Identification Displays

- Helmet Sight -- The azimuth and elevation channels of the helmet sight are used to position the identification device pointing direction.

- HMS/D Mode Control (one mode required)

  Identify -- The helmet sight azimuth and elevation angles are connected as commands to the respective axes of the identification device gimbal system. The output of the identification device vidicon is presented on the helmet display along with cues of the radar pointing direction if the radar is locked to the target.

- Acquisition Control -- When the target is within the gate of the tracker, operation of the acquisition control locks the tracker to the target and breaks the command links between the helmet sight and the identification device gimbals. The output of the video circuits remains on the helmet display along with the radar cues.

HMS/D Design Factors - Identification -- In the concept outlined for control of the identification device, the device is controlled by the helmet sight rather than being directly slaved to the radar. A direct tie to the radar would be a faster means of aligning the identification device to the target provided that the accuracy of the radar direction angles is sufficient to place an image on the identification device vidicon. To provide for visual identification at very long ranges, the telescopic sensor will necessarily have a small field of view, probably much less than 2 degrees. In present radars, directional errors of as much as 2 degrees are not uncommon. With these equipments tied together, it would be possible for the systems to be nominally aligned and still not have the target in the identification device field of view.

The choice between the control of identification device pointing angles by the helmet sight or by direct tie to the radar may be made on the basis of the radar pointing angle accuracy and the field of view of the identification device. If the identification device is slaved to the radar, an alternative connection to the helmet sight is desirable to allow identification when the radar is inoperative.

The ratio of head motion to identification device gimbal motion should be one-to-one to provide the best operation. Use of the one-to-one ratio results in the pilot's head being directed to the sight line to the target in the real world when he is following radar cues to the target. Under these circumstances, when the target becomes visible to the unaided eye, the pilot will be looking at it. In the case where the target is visible but cannot be identified with the unaided eye, the one-to-one ratio allows the identification device to be brought to bear on the target by sighting directly on the target.

The accuracy of the helmet sight is not a critical factor in the implementation of this application. The pilot will aim the sight toward the radar cue (or the actual target if he can see it) and will then search around it until the magnified image appears. Since the feedback of target image is directly before him, the absolute pointing accuracy of the components in the loop need only be good enough that any discrepancy between cue and image is small enough to avoid confusion. If overall error is less than the angular radius of the identification device field of view, the device image will always appear on the screen when the cue is at its center. System accuracy may therefore be determined by sensor field.

The field of view and resolution requirements for this application are dependent on the sensor field of view and the magnification as well as on the system requirements for identification range. If the sensor field of view is small and completely fills the vidicon screen, then a large display field will not be required. A certain amount of "electronic magnification" can be applied, but the amount which can be used is limited. An overall display field of view of less than 10 degrees is likely. The display resolution is dependent on that of the sensor and should be somewhat greater. The overall resolution of the system (sensor, electronics, and display) must be sufficient that the magnified image of the target be identifiable at the extreme design range of the identification system.

Computation Requirements -- During radar search, no HMS/D computations are required since only display functions are carried out and the display is centered on the screen regardless of the direction of the pilot's sight line. When the radar acquisition mode is commanded, computation is required to convert the head-position angles to commands for the antenna azimuth direction and the range gate position. No computation is required for the display until after the radar is locked.

After the radar is locked, the radar gimbal position signals and the helmet sight pointing angles are compared to determine the direction the helmet sight must be moved to bring it into line with the radar. The result of this computation is then converted into selection commands for cue symbols (one symbol if the radar line is off the display and a different symbol if it is on the display) and direction commands controlling either the pointing direction or the location on screen of the radar direction cues. Blanking of the radar cue near the center of the display is also controlled by calculation of the relative positions of radar sight line and helmet sight direction.

In the identification mode, calculation of radar cue position, selection, and blanking are required as in the radar acquisition mode. Calculation of identification device pointing angles from helmet sight direction angles is less complex than calculation of radar commands because of the one-to-one relationship between sight and tracker pointing angles. If compatibility between the two devices is assumed, no calculation is required. At worst, only those calculations needed to provide signal compatibility are required.

Advantages and Disadvantages -- The main advantage of the approach to long-range identification is that one man can perform functions that presently take two men. Furthermore the pilot can perform the function rapidly while maintaining visual contact with the combat situation.

This system has a good potential of meeting the performance objectives stated in Table XIX of Volume II. It has the potential of performing as well or better than the two-man system described in Reference 1.

The main deficiency of the system is the requirement for visual search around the radar cue. By proper selection of tracker field of view and provision of a nominally accurate helmet sight, this problem may be minimized.

Missile Firing - General Considerations

Missiles fired from aircraft may be of several basic types. They are often categorized by their range -- either long-, medium-, or short-range. They may also be categorized by the type of guidance used -- infrared, radar, or television. They may further be categorized by purpose -- air-to-air air-to surface, etc. From the standpoint of use of the HMS/D in the process of launching missiles, the range and purpose of the missile is of less interest than the type of guidance. The prefiring interface with the fire control system is heavily influenced by this factor.

The F-15 missile complement has not been fully defined at this time, so specific relation of the HMS/D to the F-15 system cannot be made. It is probable, though, that the missile complement finally chosen will be drawn from three types of guidance -- infrared homing, semi-active radar homing, or passive electro-optical homing.

Present day infrared homing missiles require little more from the HMS/D system than the fast, accurate lock of the radar system from which they gain their original pointing direction. With the radar (or other aircraft sensor) locked to the enemy, it is only necessary to satisfy range and acceleration requirements before firing the missile. Use of the HMS/D to set up these prelaunch conditions is discussed elsewhere and will not be repeated here. HMS/D usage in firing semi-active radar and electro-optical missiles is discussed in the following subsections.

Missile Firing - Passive E-O Homing Missiles

General Concept -- A good potential system providing the performance required of a short-range missile couples a high-performance missile with an electro-optical tracker and utilizes the HMS/D to accomplish prelaunch lock to the target. A block diagram of such a system is shown in Figure 4.

Operational Procedure -- The following operational steps are required:

- Pilot visually sights the target and places the helmet sight reticle over it.
- Missile tracker is slaved to the helmet sight.
- Missile seeker output is presented on the helmet-mounted display; display consists of the sensor video and a tracking gate.
- Pilot steers the tracking gate to the target by moving his head.
- Seeker locks when a signal of sufficient contrast is within the tracking gate.
- Pilot fires missile when range requirement is met.

Information Displayed -- The most useful display information includes target image, range data, tracking lock-on verification and radar pointing direction A possible display format is shown in Figure 5.

The use of the display is similar to that described for the long-range identification device. The radar direction cues shown in Figure 3 and the associated text may be used in an identical manner with this display. At short ranges, however, the radar is used primarily for ranging rather than location, and is not absolutely needed to launch missiles. The range display shows present

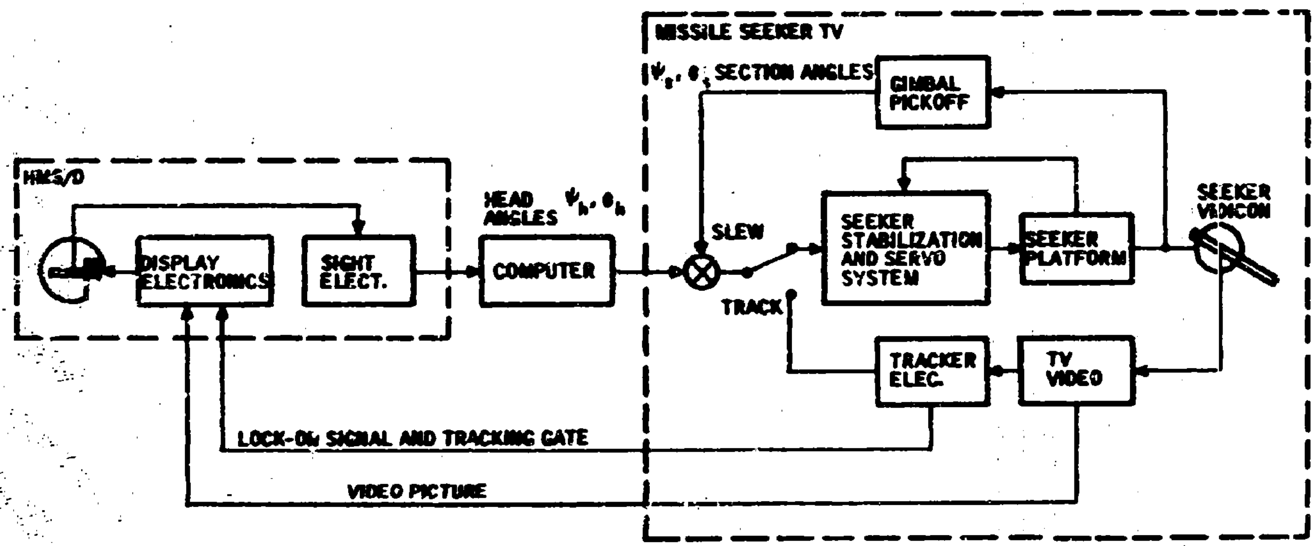


Figure 4. Electro-optical Tracker Guided Missile System Concept

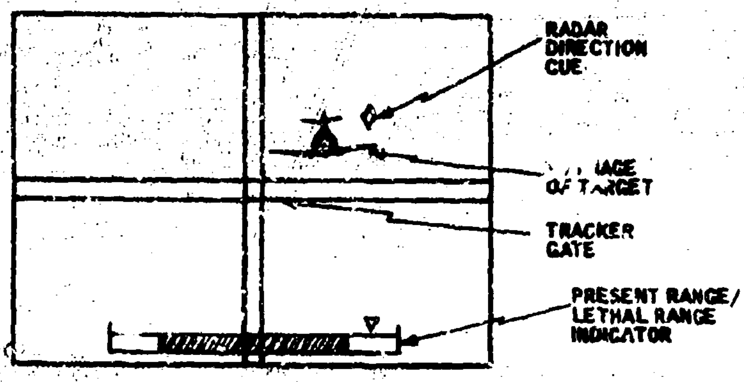


Figure 5. Typical E-O Missile Launch Display

range to the target and lethal range envelope for the missile to be fired. Tracker lock to the target is shown by the fixing of the target to the cross-hairs but may also be signalled by the appearance of a discrete symbol on the display or by disappearance of the gate symbol.

<u>Controls</u> -- The helmet sight is used to direct the missile's E-O tracker to the target. Azimuth and elevation channels of the helmet sight are connected at a one-to-one scale to the respective gimbal drives on the tracker. Thus, when the pilot looks at the target he is also pointing the tracker at it. For short-range missiles, this will likely be the normal method of aiming. In addition to the helmet sight, three controls are required:

- <u>HMS/D Mode Control</u> (one mode required)

  E-O Missile -- The helmet sight outputs are connected to the missile tracker gimbals, commanding position at a one-to-one ratio of head motion to gimbal motion. The video output of the E-O tracker, which includes the tracking gate symbol, is placed on the helmet display. If the radar is locked, radar direction cues and present range are also displayed. The lethal range envelope for the missile is preprogrammed and selected by the choice of weapons.

- Acquisition Control -- When the necessary contrast elements of the target are in the tracker gate, operation of the acquisition control locks the tracker to the target and breaks the command links from the helmet sight. If a discrete indication of tracker lock is used, feedback from the tracker is used to command the symbol onto the display.

- Firing Control -- When the missile tracker has been locked to the target and the range requirement for launch has been met, operation of the firing control releases the weapon. The firing control is interlocked through the HMS/D mode control such as to allow the pilot to arm those weapons he expects to use in an engagement beforehand and make the final selection of weapons by the setting of the HMS/D mode.

HMS/D Design Factors -- The factors influencing the HMS/D display for this application are similar to those influencing the long-range identification video system. The field of view of the display should be at least as great as the real-world field of view of the sensor and possibly larger depending on sensor magnification. Resolution of the display should be slightly better than that of the sensor, and resolution of the overall system should be similar to that of the long-range identification system. Accuracy of the helmet sight/tracker gimbal system again need not be extremely fine since the application is a closed loop, with the pilot able to check on the actual pointing of the sensor by observing the target image on the screen. In the worst case, overall accuracy equal to the angular radius of the sensor field of view would be usable; however, it might result in some confusion to the pilot as he saw the real-world target at the edge of the screen while the sensor image was at the center. System pointing accuracy on the order of half the sensor field radius should avoid this problem. Since the missile tracking sensors are likely to have wider angular fields than the identification telescope, this may not indicate a tighter tolerance than is required for long-range identification.

Since the missile launching process will probably be accomplished at short ranges, the target aircraft will normally be visible to the unaided eye. The most desirable approach will be to sight on it directly, and, to do this most easily, a display which allows the pilot to look through the display at the target is desirable. This allows him to use the missile tracker gate as a sighting reticle and line up on the target directly. Direct view of the target by the same eye which sees the display should minimize difficulty in use of the equipment. The pilot's attention will probably alternate between the real target and the display, and the "see-through" mechanization should allow this alternation with the least difficulty.

Since the range to the target is a very desirable parameter to have during a missile attack, and since the time to take multiple steps during a close-in engagement is severely limited, consideration should be given to a tie to the radar which would bring it to lock along with the E-O missile tracker. This approach, if mechanized, would allow the short-range attack to begin in the E-O missile mode and in one operation bring both sensors to bear on the target.

The preferable mechanization would be to tie the radar to the tracker since tracker lock is likely to require less time than radar lock. Once the tracker locks, it would hold the radar in line long enough to allow it to lock also. The display would provide direct indication of radar lock by appearance of the range and cueing symbols.

Advantages and Disadvantages -- The use of the HMS/D in this application offers the primary advantage of allowing the entire attack to be made without looking down into the cockpit. Particularly, if the tie to the radar is made, the weapon and range sensors are simultaneously locked to the target, and all information relevant to release of the missile are presented directly to the pilot. The system is particularly good at discriminating among multiple targets, and it has the advantage of automatic compensation for sighting errors and wing flexure errors which would affect an open-loop system.

The system is at a disadvantage under conditions of bad visibility when clouds or overcast may prevent sighting or lock of the missile tracker. Unless the missile tracker is capable of operation under very low-light-level conditions, the system is not usable at night unless some type of illuminator is provided. Provision of a missile tracker that is capable of low-light-level operation is not out of the question, and with such a tracker the tie between radar cueing and through-the-missile sighting offers a means of extending the period of operation well into conditions of dusk if not to complete darkness. The system appears to meet the requirements of Table XX of Volume II of this report.

Missile Firing - Semi-active Radar Homing Missiles

General Concept -- The HMS/D can be used with a semi-active homing missile such as the AIM 7 (Sparrow). The display provides a capability to verify what the radar is locked to and presents range and lethal envelope information. A block diagram of the system is shown in Figure 6.

Operational Procedure -- The following operational steps are required:

- Pilot sights the target with the helmet sight.
- Radar is servoed to align with the helmet sight.
- Pilot operates the acquisition control, and the radar searches a small field around the helmet sight direction.
- Radar acquires the target.
- Radar tracking direction is displayed on the helmet display along with range and lethal envelope.
- Pilot fires the missile when range requirements are met.
- Pilot uses the helmet sight to maintain target illumination during missile flight.

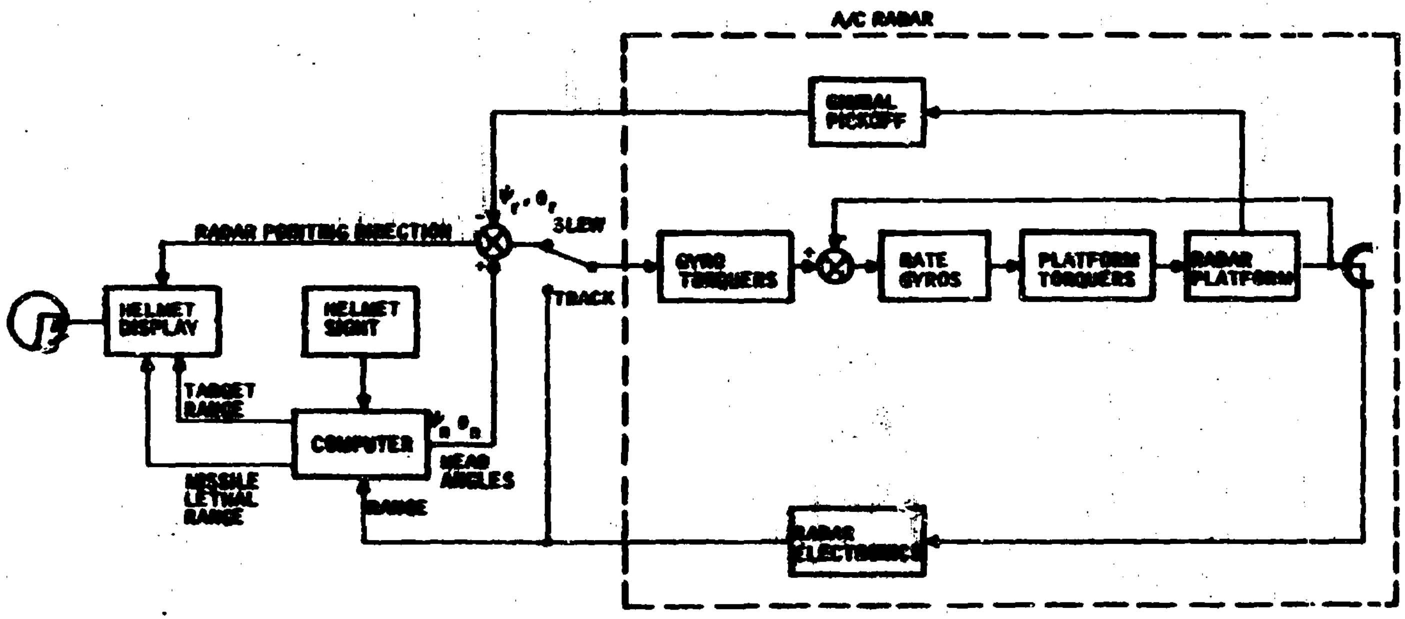


Figure 6. Semi-active Homing Missile System Concept

Information Displayed -- The displayed information includes radar pointing direction, target range, and lethal range envelope. A possible format is shown in Figure 7.

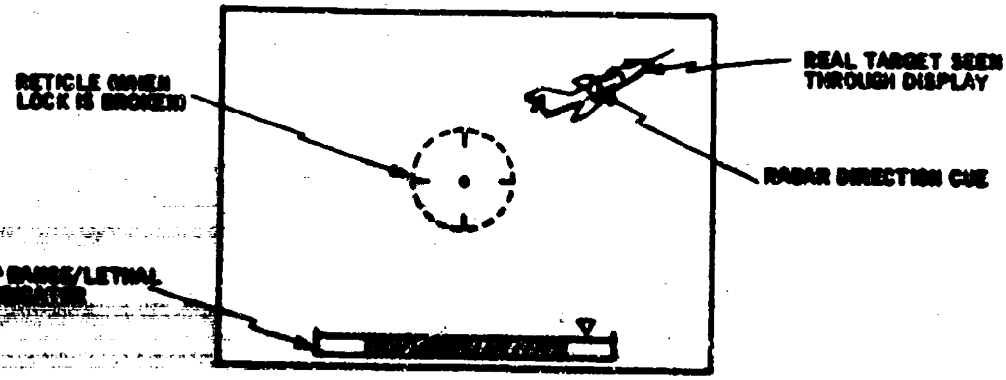


Figure 7. Possible Semi-active Missile Launch Display (after radar lock)

If the radar has been locked to the target previously, the radar direction cues and target range/lethal range displays described previously appear on the display. Verification of lock to the correct target is made by looking at the target through the display and noting that the direction cue lies over the target. In the event that radar lock is lost while in this mode (or if lock has not been achieved when the mode is selected), the direction cues and target range are not available. Instead, automatic selection of a quick radar lock mode is made, and a sighting reticle is presented on the helmet display. Radar lock is brought about by sighting the target. Re-establishment of lock automatically returns the display to its original condition. The use of the quick lock mode for the radar is necessarily restricted to short ranges where an automatic range gate can be used.

Controls -- During the radar quick lock mode, the helmet sight controls the pointing direction of the radar such that the radar points where the pilot is looking. Control of the transfer between radar quick lock mode and missile firing mode is automatic and is dependent only on whether the radar is locked. Three manual controls are also required:

- HMS/D Mode Control (one mode required)

  Semi-active -- If radar is locked, radar direction cues and target range/lethal range indicator are displayed. If radar is not locked, a sighting reticle is placed on the display and

the azimuth and elevation outputs of the helmet sight are connected on a one-to-one scale to the respective gimbal drives of the radar. Transfer between the two possible conditions is automatic as the radar locks and unlocks.

- Acquisition Control -- When the radar has been aligned to the target by the helmet sight, operation of the acquisition control causes the range gate to move to the target. Lock to the target is automatic when the range gate reaches it.

- Firing Control -- When the radar is locked to the target, illuminating it for the missile, and the launch range requirement for the missile is met, the pilot fires the missile by operating the firing control. The firing control is interlocked through the HMS/D mode control such that the pilot may arm all the weapons he expects to use during an engagement and make the final selection as to which will be fired by setting the HMS/D mode. An interlock is also provided to prevent launch of a missile before the radar is locked.

HMS/D Design Factors -- This application imposes no new requirements on display size or resolution. The display presentation is entirely symbolic and requires only coarse resolution. The display field of view need be only large enough that the symbols can be conveniently arranged without interfering with each other. A 5-degree field should be satisfactory for this purpose.

Helmet sight accuracy requirements will depend on the type of radar used and more particularly on the beam width and the arrangements made for scanning the beam around the nominal sight line during acquisition. Present radars can be expected to lock to targets more than 2 degrees off their nominal sight lines An overall accuracy for the helmet sight/radar gimbal system of 1.5 to 2 degrees is probably satisfactory for this application.

Computation Requirements -- The computations required for this application have been described previously. They include the selection and location of directional cues, the selection and location of target range/lethal range display components, and the translation of pointing commands from helmet sight output format to the format required by the radar gimbal drive. A new computation function required in this application is the sensing of the presence of the radar lock signal and the selection of the proper mode connections for the sight and display.

Fixed Gun Firing

The HMS/D can be used in a fixed gun control system to lock and relock the radar to the target, to replace the present head-up display in presenting the desired gun lead angle command, and to determine target line of sight with respect to the attacking aircraft.

There are three approaches to mechanizing a fixed gun system:

The currently used lead computing optical sight (LCOS) presentation may be employed. Information can be displayed on either the head-up display or the helmet display and the helmet sight used to steer and lock the radar.

The helmet sight can be used to direct and lock the radar to the target and the radar then be used to give target range and relative angular rate for a director gun sight solution.

The helmet sight can be used to steer and lock the radar to the target, and the target rate for the director sight can be calculated from the aircraft rate gyros plus changing helmet sight angles as the pilot continues to track the target.

In the latter two approaches, either the head-up display or the helmet display may be used to display the aircraft steering signal which establishes the desired lead angle. Both these approaches result in a director sight rather than the traditional LCOS, and both should give better results if they can be implemented.

A vital part of the operation of all three concepts is the ready availability of the radar, locked to the target and providing range data. Failure to lock the radar or to keep it locked once the engagement has been started is one of the most serious problems in present day aerial combat. The HMS/D quick radar lock mode described in the section on semi-active missile attack offers a rapid means of locking the radar and can form a part of any of the three concepts chosen.

The LCOS concept has shown itself to have a number of disadvantages. Fire control computation is based on measurement of the angular rate of the attacking aircraft and assumes this to be the rate of the enemy. The assumption is true only when the attacker is tracking the enemy, and it results in large errors during the period when the attacker is coming into position to begin an attack. These errors take the form of large fluctuations in the sight reticle position and result in both false indications of firing opportunities and failure to indicate true firing opportunities. Because of these deficiences, the best opportunity for improving gun fire accuracies is to implement a director sight system which actually measures the angular rate of the enemy aircraft.

Of the two director sight concepts outlined above, the one which utilizes radar angular rate information is more desirable from the standpoint of the pilot. The other concept in which the rate of the opposing aircraft is taken from the helmet sight as the pilot tracks the target, imposes a very difficult task on the pilot. Figure 8 illustrates the problem. To secure continuous

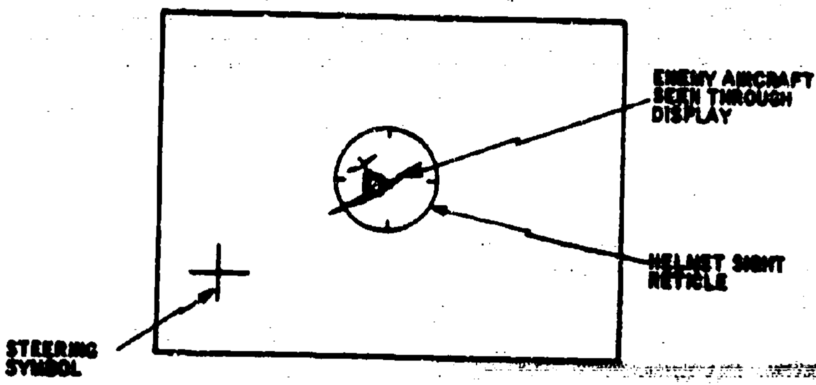


Figure 8. Director Gunsight Display Requiring Continuous Tracking with HMS/D

rate information on the enemy aircraft, the pilot must continuously track him with the helmet sight. This in itself may be a difficult task; but, in addition, the pilot must try to steer his own craft in order to line up a steering symbol which indicates the position in which the proper lead angles exist. The combination of the two difficult tasks is undesirable and should be avoided if possible. By taking the opposing aircraft's rate from the radar, one of the tasks can be eliminated. For that reason, the second of the three concepts outlined seems to offer the greatest opportunity for being both achievable and an improvement of the gun fire control situation over that now existing.

General Concept - The helmet sight is used in the quick radar lock mode to lock the radar to the target and to relock it as necessary during the continuing engagement. Both range and enemy aircraft angular rate are derived from the radar angle outputs. The director sight computations are performed by the fire control computer which generates commands to position a steering symbol display. The gun sight symbol is presented on the helmet display and is stabilized to the armament datum line of the aircraft by feedback of the helmet sight angles. After the radar is locked, the pilot guides his craft to

bring the steering symbol into line with the enemy. A block diagram of the system is shown in Figure 9.

Operational Procedure - The following operational steps are required:

- Pilot locks the radar to the target using the quick radar lock mode.

- Radar provides target range and relative angular rate measurements.

- Fire control computer solves the director sight computations and commands the position of the steering symbol on the display.

- Pilot steers the aircraft to place the steering symbol over the enemy craft.

- Pilot fires guns when the symbol lines up with the enemy.

- Pilot relocks the radar as necessary during the engagement. Transfer between the gunsight and quick radar lock displays is by manual selection. Return to the gunsight display is automatic with relock.

Information Displayed - The information required for the quick radar lock mode was described previously -- a simple sighting reticle for pointing the radar at the target. After lock of the radar, the cues and range display previously associated with radar locking tasks may be despensed with. No cues are needed since the enemy is at close range. No range display is required because the range is used in calculating the lead angles which are then displayed. A single steering symbol is presented for the gunsight display. Figure 10 shows a possible display format. In the event that the radar unlocks during the engagement, the normal action would be to re-establish lock. It is possible, though, that if unlock occurred just as the guns were to be fired it would be desirableto continue with the attack rather than being suddenly faced with a different display. For that reason, the transfer between the gunsight display format and the quick radar lock format should not be automatic. Neither, however, should it require the pilot to look down into the cockpit. A suitable arrangement is to utilize the acquisition control in a toggling circuit which allows it to command the two formats alternately. An unlock warning is required on the gunsight display to show when relock is needed. No similar discrete is needed on the quick lock display since the change to the gunsight format is automatic with radar lock.

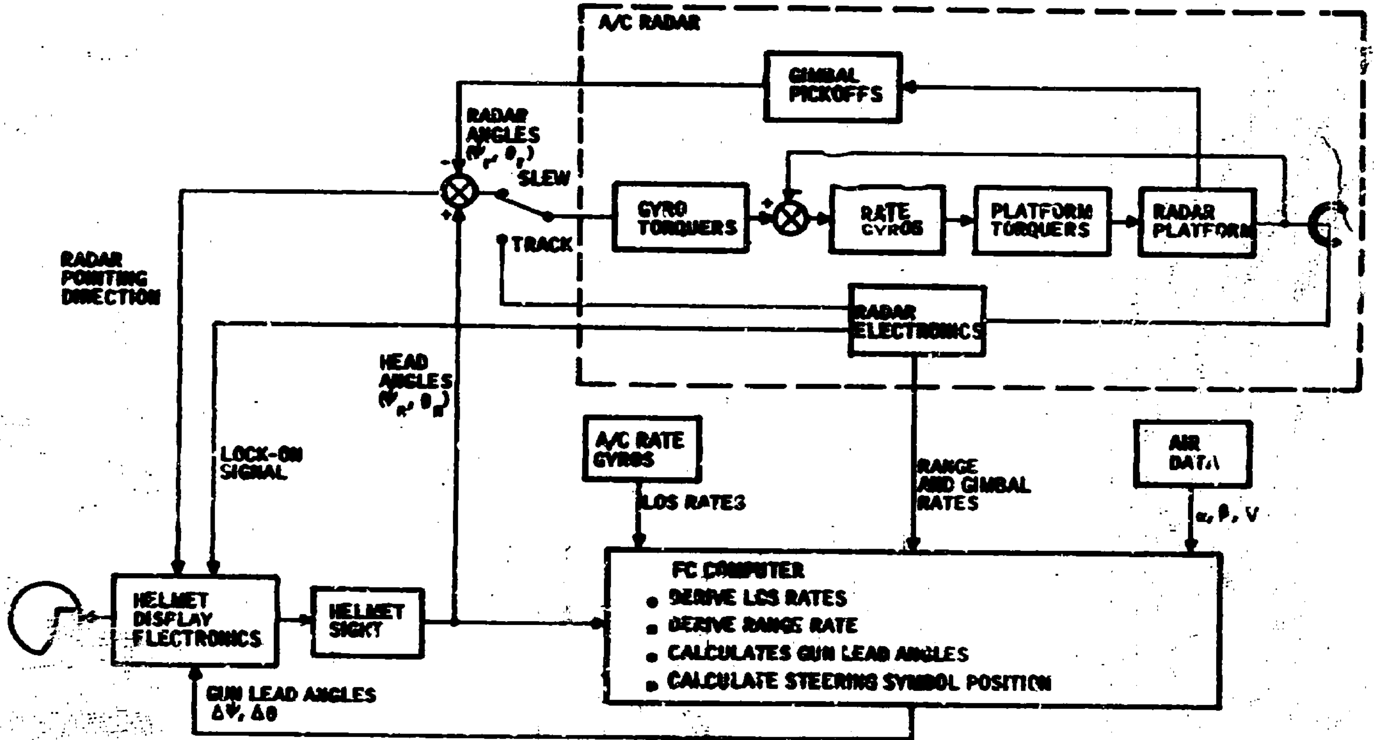


Figure 9. Fixed Gun Firing System Concept

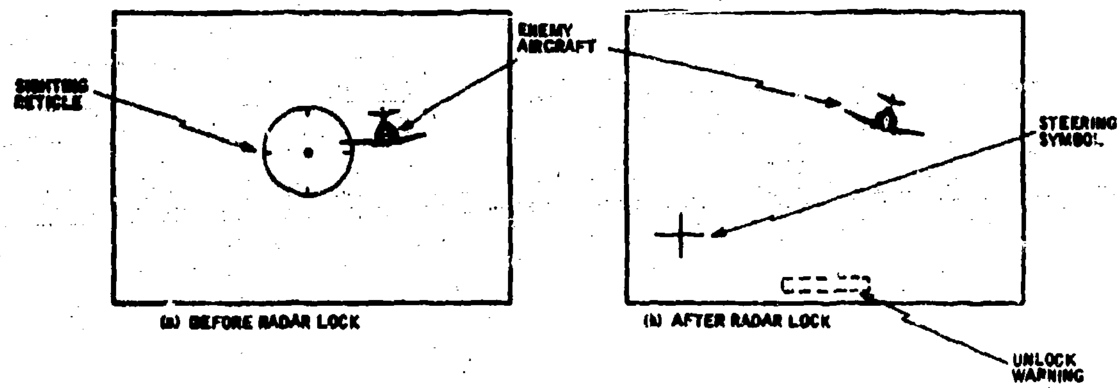


Figure 10. Possible Director Gunsight Display

<u>Controls</u> - The helment sight is used to direct the radar to the target during the quick radar lock portion of the task. During the time that the gunsight display is on the display, the helmet angles are used to move the entire display such as to maintain its alignment with the aircraft armament datum line. Three other controls are required:

- <u>HMS/D Mode Control</u> (one mode required)

  Guns - If radar is not locked, the helmet sight outputs are coupled to the radar gimbal drive on a one-to-one scale. A sight reticle is presented at the center of the helmet display.

  If the radar is locked, the helmet sight angles are used in the fire control computer as a correction on the position of the steering symbol in order to maintain it in the correct relation to the armament datum line. The steering symbol is displayed on the helmet display.

- <u>Acquisition Control</u> -- If the radar is not locked, it will be directed toward the target by the helmet sight and locked to the target by operation of the acquisition control. At the short ranges involved with gun engagements, an automatically positioned range gate may be used. If the radar has been locked and for any reason unlocks, a warning of the condition appears on the gunsight display. In this condition, operation of the acquisition control causes the quick radar lock mode to be re-established.

- Firing Control -- When the gunsight steering symbol has been aligned with the target, the firing control is used to fire the guns. As in other weapon applications, the firing control is interlocked through the HMS/D mode control to ensure the firing of the weapon for which the sight mode has been selected.

HMS/D Design Factors - The field of view required for the helmet display is determined by the amount of lead angle required for the gun fire solution, since the steering symbol must be deflected through those angles. Lead angles on the order of 10 degrees may be expected, and, since the display must be capable of this deflection in any direction, a total field of 20 degrees is called for.

Helmet sight accuracy required for this application is set not by the radar pointing function, which need be no better than that described previously, but rather by the need to stabilize the display relative to the aircraft armament datum line. Any error in this stabilization is a corresponding error in the aircraft steering symbol location. A goal of zero helmet sight error in the center 10 to 20 degrees of its active range is desirable. With the present state of the art, errors corresponding to an error of 8 or 9 feet at the extreme range of existing guns are feasible over this range.

Another factor bearing on the overall implementation of the director sight using radar angles is the difficulty which has been experienced in securing noise-free angular rate from radars. The use of the concept is dependent on noise-free rate signals. In the event that the radar to be used in the particular aircraft cannot deliver the required signals, alternative sources must be explored, or a different approach must be taken. In this regard, a potential contender would be the quick reaction or "hose type" sight which calculates and displays the bullet trajectory and allows aiming with a technique similar to that used with tracer bullets.

Computation Required - Other than the basic fire control computation, only the computation needed to allow the helmet sight to direct the radar pointing angles is required. The computation of lead angles takes the form:

$$\Delta\psi = -(w_{z_r})t_f + \frac{\beta K_o R}{2} + \frac{g \sin\phi \cos\theta R}{(V_m + V)^2}$$

$$\Delta\theta = -(w_{y_r})t_f + \frac{\alpha K_o R}{2} + \frac{g \cos\phi \cos\theta R}{(V_m + V)^2}$$

and t_f is determined from

$$R = \frac{1}{K_o}\ l_n\ [1 + K_o\,(V_m + V)\,t_f] - V_{t_f}$$

where:

w_{y_r}, w_{z_r} = enemy rate measured from radar angles

α, β = angle-of-attack and sideslip

R = range measured by radar

V_m = gun muzzle velocity

V = aircraft velocity

t_f = bullet flight time

K_o = bullet constant

ϕ, θ = roll and pitch angles of aircraft

Advantages and Disadvantages - The use of the HMS/D in the firing of guns offers a great advantage in allowing the rapid lock of the radar to the target. By making the radar range available, the computation of a solution to the fire control equations will be improved no matter what sight mechanization is used. If the problems associated with the generation of a satisfactory rate signal from radar (or other sensor) tracking data can be solved, the greater assurance of having the sensor locked to the target makes the implementation of the director gun sight a possibility.

The principal disadvantage of the helmet sight/display in this application is the small error allowance for the positioning of the display relative to the armament datum line. This may impose very strict requirements not only on the HMS/D system performance but on the physical alignment of components in the aircraft.

AIR-TO-GROUND COMBAT APPLICATIONS

Air-to-ground combat applications considered were: (1) long-range target acquisition and identification; (2) target location and navigation updating; (3) missile firing; (4) fixed gun firing; and (5) bombing.

Long-Range Target Acquisition and Identification

General Concept - In attacking ground targets, visual target acquisition and identification is of great importance since radar displays are often badly cluttered. The use of the long-range electro-optical identification device for target identification is a very likely mode of operation for any aircraft equipped with such a device. The HMS/D would be used in much the same manner as described under air-to-air combat applications, with the exception that radar cues to guide the identification device to the target would seldom be available. By scanning the ground visually, the pilot would pick out the area of interest to him. He would then point the identification device to these areas, using the helmet sight, and would see the video presentation from the identification device on the helmet display.

Operational Procedure - The following operational steps are required:

- Pilot scans the ground for potential target areas
- Pilot uses the HMS/D to sight on areas of particular interest
- Output of the identification telescope is presented on the helmet display
- Pilot identifies the target; he may lock the identification device tracker to the target if he wishes
- As an option, pilot may direct the radar simultaneously with the identification device to measure range to the target

Other Factors - The controls required, HMS/D design factors, and computation required for this application are essentially the same as those for the air-to-air application.

Target Location and Navigation Updating

General Concept - Coordinates of points on the ground may be determined by use of the HMS/D in combination with the central aircraft computer and the inertial navigation system. By repeated sighting as the aircraft moves, data may be taken to allow location of the ground point by triangulation. The technique may be used either to locate a ground target in such a way as to allow return to the target for a later attack or to insert data on navigation checkpoints into the position update computations. Both uses of the HMS/D have been thoroughly tested during flight tests conducted as part of the TACREACT program (Reference 2). A block diagram of a system for this purpose is shown in Figure 11.

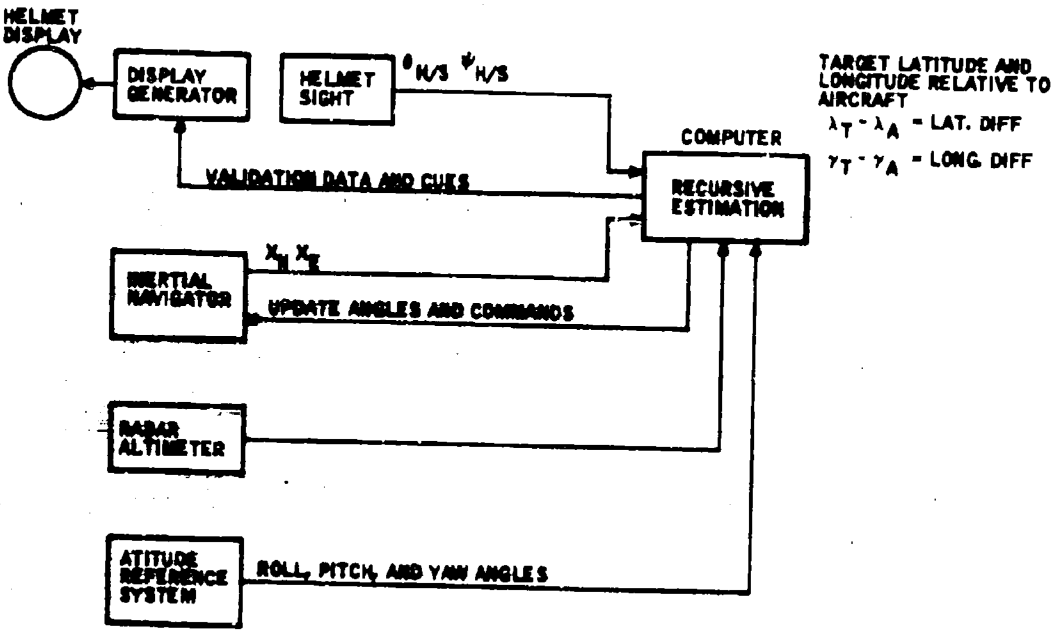


Figure 11. Target Location and Navigation Update Concept

Operational Procedure - In the navigation update mode the operational procedure includes:

- Pilot sights checkpoint through helmet sight
- Pilot sets switch to begin update; readings of angles to the target are taken automatically at a rate of 5-10 per second
- Pilot releases switchto stop data acquisition
- New position and update position are calculated and displayed for pilot verification
- Switch is set to insert update coordinates

In the target location mode, the pilot procedure is the same as for navigation update except that after the target has been located, the pilot maneuvers to attack guided by cueing symbols on the helmet display.

Information Displayed - For daytime use, a target reticle must be displayed while the pilot is sighting on the ground point. The navigation update validity check data may be presented on the helmet display or on the navigator control panel. Since the navigation update task is performed under less demanding circumstances than the combat tasks previously discussed, it is possible for the pilot to look down into the cockpit without penalty during this task. For night operations, the same procedure may be used if the checkpoint is illuminated or can be identified in the dark. Otherwise, a pointable sensor with its output presented on the helmet display is required as a guide to sighting.

For target location, the position of the target is compared with the aircraft position, and the error signals are used to position cues to direct the pilot back to the target. The same cueing symbols discussed previously for indicating radar direction may be used for this purpose. An additional cue is required if it is desirable to indicate that the target is behind the aircraft and therefore out of the range of the pilot's head motion. Figure 12 shows a possible sequence of cueing signals for this purpose.

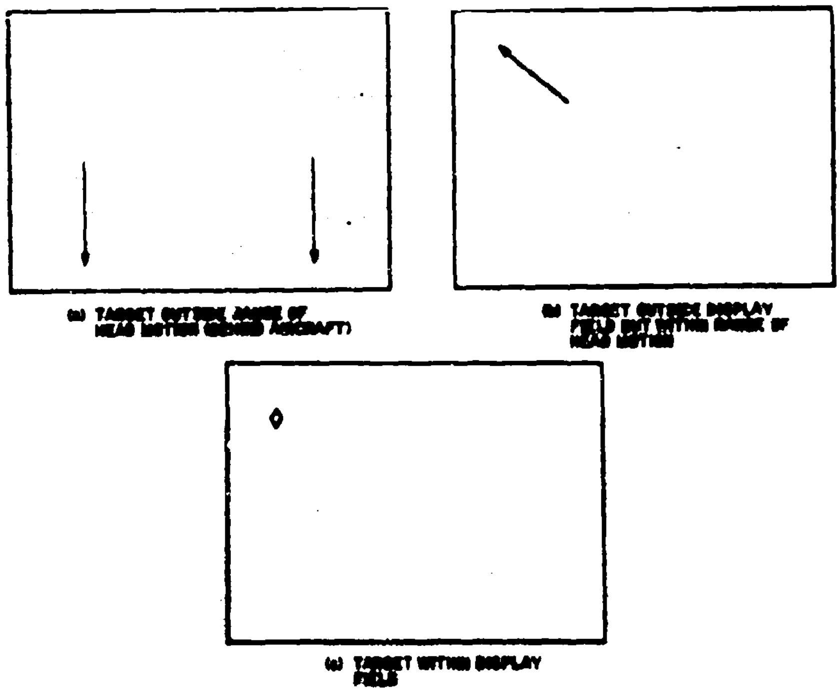


Figure 12. Possible Ground Target Location Cues

Controls Required - For either target location or navigation update, the helmet sight provides data inputs to the position computation. If a pointable sensor is used for night operation, the helmet sight is used to direct it to the target. In addition to the helmet sight, the following controls are required:

- HMS/D Mode Control

  Target Location - The helmet sight outputs are connected to the computer to provide data for the location calculations. Target location cues are placed on the helmet display and located in accordance with computer command

  Navigation Update - The helmet sight provides the same function as in target location. The information required for update validity check may be displayed on the helmet display if desired

In both modes, the outputs of the helmet sight may be used to point a sensor (low-light-level TV or IR) for night observation of the ground target. If this is done, the video output of the sensor is presented on the helmet display.

- Acquisition Control - Operation of the acquisition control while the pilot is tracking the target with the helmet sight causes the computer to take repeated readings of the helmet sight angles as long as the control is operated. The control also starts the calculation selected by the mode control.

- Navigation Update Control - After the update calculations have been completed and the new position has been checked for validity, operation of the navigation update control inserts the corrected aircraft position into the navigation system. This control is actually a part of the navigation system rather than the HMS/D system.

Computation Required - Two different approaches to the calculation of targets on the ground have been used with helmet sight systems: (1) triangulation and (2) altitude-range. In the triangulation method a minimum of two sights and the measured distance travelled between sights are required to determine the planar position of the target. Additional sights and distance measurements improve the measurement of target position. By making a series of angle and distance measurements at short intervals during a fly-by and by using appropriate filter techniques, an optimum measurement of target position is derived.

The altitude-range method of target location uses the bearing and depression angles to the target and the radar altitude of the aircraft. A single sight is required, though the measurement is improved if the target is sighted repeatedly and the series of calculations averaged to get the actual position. This method is most accurate over flat terrain where the target is at the same elevation as the point immediately below the aircraft.

Both methods provide target position in aircraft coordinates. An additional angular transformation is required in order to get navigation coordinates for the target. This transformation requires knowledge of the aircraft pitch, roll and yaw angles which may be supplied by the attitude reference system.

HMS/D Design Factors - No new design factors for the HMS/D itself are introduced by this application.

Advantages and Disadvantages - In present air-to-ground attacks, the approach to the target is limited to particular angles from the aircraft, and many attacks require a run toward the target. Comments from pilots indicate that the defenders on the ground are aware of the limitations on tactics and are well prepared for them. If a second run on a target is required, the chances of damage to the aircraft are high. The use of the HMS/D offers a means of broadening the limits on air-to-ground attack tactics. The additional load of computation needed to provide both target location cues and navigation update calculations is a slight disadvantage in terms of computer capacity required.

Missile Firing

Mission performance objectives of high-speed aircraft for air-to-ground missile delivery include: offset delivery capability, quick reaction, and launch and leave capability. These objectives may be met by use of the helmet-mounted sight and display to steer and lock-on TV seekers similar to those used in the Walleye missile. The HMS/D can be used to overcome some of the difficulties of the Walleye system. These difficulties include the requirement that the aircraft be pointed at the target to accomplish seeker lock-on and the requirement that the pilot view the aircraft vertical situation display while accomplishing lock-on.

Improved performance could be obtained by mechanizing of an HMS/D-Walley system similar to the E-O guided missile-HMS/D system described in the subsection on air-to-air combat shown in Figure 4.

The operational procedure thus would be:

- Pilot visually acquires and identifies the target
- Pilot sights the target through the missile TV tracker and steers the tracking gate to the target

The controls and displays required for air-to-ground missile delivery of an electro-optical contact tracking missile is very similar to that discussed for the air-to-air E O guided missile discussed previously.

Bombing

The HMS/D in conjunction with an accurate target tracker can be used to provide accuracy of unguided air-to-ground weapons such as bombs or cluster munitions.

Assuming that the E-O identification device has been locked to the target during the acquisition phase, this tracker could provide angular rates for the bombing solution while the radar, slaved to the tracker, provided continuous target range. As an alternative, a laser rangefinder may be used in place of the radar.

For visual dive bombing, the sight line must be compensated for windage. The compensation requires inputs from the aircraft attitude reference and air data computer systems. A separate mode of HMS/D operation is indicated here. The mechanization of this mode requires the definition of a sight line in a fixed relation to the armament datum line much as in gun firing. The difference is in the compensation applied to the sight line. Thus, the only difference between the two modes of operation is in the computation, and there need be no difference in the display.

Concept Summary

The preceding concepts for use of the HMS/D entail many relationships between aircraft components, many possibilities for displays, many possible combinations of sensors, and many possible combinations of controls. To summarize the information contained in the concept definitions, Table I provides information on these variables in outline form. The table provides references to the figures and text which concern the various applications.

Table I. Concept Analysis Su

Application	Concept	Block Diagram	HMS/D Interfaces With	Information Displayed	Controls Required	
Radar search	Radar plot shown on helmet display	Figure 1	Radar	Radar plot	Mode	
Radar acquisition (long-range)	Radar plot shown on helmet display. Radar azimuth and range gate location controlled by helmet sight.	Figure 1	Radar	Radar plot Gate symbol Cues and range (after lock) (Figure 2)	Mode Acquisition Antenna elevation	He An c Cu c
Target identification	E-O tracker video shown on helmet display. Tracker pointing controlled by helmet sight	Figure 1	Radar Identification device	Radar cues Tracker video Range (Figure 3)	Mode Acquisition	He Tr c Cu c
E-O missile launch	E-O tracker video shown on helmet display with missile lethal envelope and present range to target. Tracker pointing controlled by helmet sight.	Figure 4	Radar E-O missile Weapon control circuits	Radar cues Range to target Lethal range Tracker video (Figure 5)	Mode Acquisition Firing	He Tr me Cu co Le co Ra co
Semi-active radar missile launch	Radar direction cues, target range, and lethal range envelope displayed. Reticle displayed to reestablish radar contact if lock is broken. Radar pointing controlled by helmet sight.	Figure 6	Radar Weapon control circuits	Radar cues Range to target Lethal range Sight reticle (if lock is broken) (Figure 7)	Mode Acquisition Firing	He Ra Cu co Le co Ra co Au co
Fixed gun firing	Radar pointing reticle and stabilized aircraft steering symbol shown on helmet display. Radar pointing direction controlled by helmet sight.	Figure 9	Radar Weapon control circuits	Reticle Steering symbol	Mode Acquisition Firing	Ra He Le Sy co
Target location and navigation update	Ground point sighted on with helmet sight. Cues for return to target shown on helmet display. Navigation update coordinates computed and placed in use on command.	Figure 11	Computer Inertial navig. Attitude ref. Radar altimeter	Reticle Direction cues (Figure 12)	Mode Acquisition Update command	Gr He Cu co Na
Bombing	Same as fixed gun firing except in computation	Figure 9	Radar Weapon control circuits	Reticle Steering symbol Range data	Mode Acquisition Firing	He Ra Le Sy ma

A

e I. Concept Analysis Summary

	Controls Required	Computation Performed	Design Factors: Field-of-View	Display Resolution	Head-to-target Motion Ratio	Helmet Sight Accuracy	Potential Link to other uses
	Mode	--	Same as radar scope	Coarse	--	--	
e(after lock)	Mode Acquisition Antenna elevation	Head position Antenna and gate position commands Cue type and position commands	Same as radar scope	Coarse	Less than 1:1. Determine by experiment	Less than radar beam width or cone cone of automatic acquisition.	
	Mode Acquisition	Head position Tracker pointing commands Cue type and position commands	Less than 10 deg	Fine	1:1	Less than the angular radius of the tracker field of view.	
t	Mode Acquisition Firing	Head position Tracker pointing commands Cue type and position commands Lethal range selection commands Range indicator position commands	Less than 10 deg	Medium	1:1	Less than 1/2 the angular radius of the tracker field.	Radar lock could be combined with E-O tracker lock
t lock is	Mode Acquisition Firing	Head position Radar pointing commands Cue type and position commands Lethal range selection commands Range indicator position commands Automatic mode change commands	5 deg	Coarse	1:1	1.5 deg to 2 deg	Quick radar lock mode useful in other applications (E-O missile and guns)
d	Mode Acquisition Firing	Radar pointing commands Head position Lead angles Symbol position commands.	20 deg or more	Coarse	1:1	Very fine	
	Mode Acquisition Update command	Ground point location Head position Cue type and position commands Navigation corrections	Small (3-5 deg)	Coarse	--	Fine	
d	Mode Acquisition Firing	Head position Radar pointing commands Lead angles Symbol position commands	10 - 15 deg	Coarse	1:1	Very fine	

B

SECTION III

PHASE REQUIREMENTS

A sequence of applications is derived for the combat phases, emphasizing air superiority. A basic system is assumed for day air-to-air operations which includes an attack radar, long-range identification device, fixed cannon, TV guided short-range missile (SRM), and a semi-active radar long-range air-to-air missile. Day air-to-ground operations are assumed to be conducted by the replacement of the air-to-air missiles with bombs and a TV guided air-to-ground missile.

Night operations are not considered as prime requirements. However, night attack sequences are included by assuming the addition of a laser illuminator for air-to-air combat and a pod-mounted forward-looking infrared (FLIR) unit for air-to-ground combat during night and degraded weather operations. Night air-to-ground operations also assume the development of a semi-active laser guided missile. The basic role of air superiority is not considered compromised if other missions may be accomplished solely by add-on capability.

Only the essential display elements were considered here. Other display elements may be added as "clutter" problems are solved. Use of the display for scene imagery is held to a minimum, while maximum use is made of simple visual cues and sighting symbols.

AIR-TO-AIR COMBAT PHASE

The air-to-air combat phase sequence starts with long-range radar acquisition continuing through to a close-in "dogfight." This sequence was assumed in order to present a total concept for the use of the HMS/D during the phase while actual combat may involve only segments of the assumed sequence. The applications considered relevant to this phase include:

- Radar lock-on
- Target position cue
- Identification device control and track
- Missile seeker control and track
- Short-range radar lock and reticle display
- Gun control

Figure 13 illustrates the assumed sequence of applications for air-to-air combat. The basic advantages with the HMS/D are the elimination of

a side stick controller, availability of line-of-sight cueing, and the fast-reaction-afforded for close-in combat.

The sequence starts with the radar in a search mode. A cursor is displayed indicating the direction for commanded lock-on. For acquisition, the pilot switches the radar display to the HMS/D while the cursor is controlled by the pilot line-of-sight (LOS). The radar display is centered in the pilot's field of view (FOV) while the cursor appears to move on the display as the pilot's head moves. In this manner, the pilot LOS assumes the role of the side stick controller. The radar scans an actual azimuth of 120 degrees while the radar display presents a much smaller FOV to the pilot.

Upon initiating radar track, the radar display will be removed, and a symbol indicating the true target position will appear on the display. This symbol (shown as a diamond) now appears fixed to the target and will appear to move off the display as the pilot turns his head away from it. As soon as the target symbol falls outside the display area, a cueing arrow will appear indicating the direction for visual reacquisition. A range indicator appears whenever the radar is locked.

The "Identify" mode is now selected to perform long-range identification. Upon selection, the identification device is slaved to the helmet sight, and video imagery is presented on the helmet display. The pilot aligns the identification device with the direction of radar-lock by centering its gate on the LOS cue (diamond). Due to a narrow FOV of the identification device and radar errors, the target image may not appear on the display. In this case, a small scan is made of the cued area until the target image does appear. As soon as the target aircraft enters the tracking gate, lock-on is commanded, and the identification device tracks the target. The image is now stable and fixed relative to the helmet so identification may be made. Angular tracking data is now available from either the radar or the tracker. The radar also provides range data. Long-range semi-active radar missiles may now be fired when range requirements are met. Selection of the missile places its lethal range envelope on the range display.

When the target comes within range of the short-range missile (SRM), selection of the "SRM" mode automatically slaves the missile's seeker to the pilot's LOS and presents the seeker imagery on the helmet display for direct viewing. The pilot locks the tracker to the target as he did the identification device. The missile's lethal range envelope is automatically displayed when the weapon is selected.

One of the problems for close-in combat is the lack of accurate tracking and range data for gun fire control since radar lock is easily broken and critical timing requirements inhibit reacquisition capability. The HMS/D is considered instrumental for off-angle radar lock-on at close ranges. This application requires that the radar antenna be guided directly by the pilot's LOS and that the range gate automatically lock on an object at short range. Steering signal is displayed and located in response to calculations for a director sight.

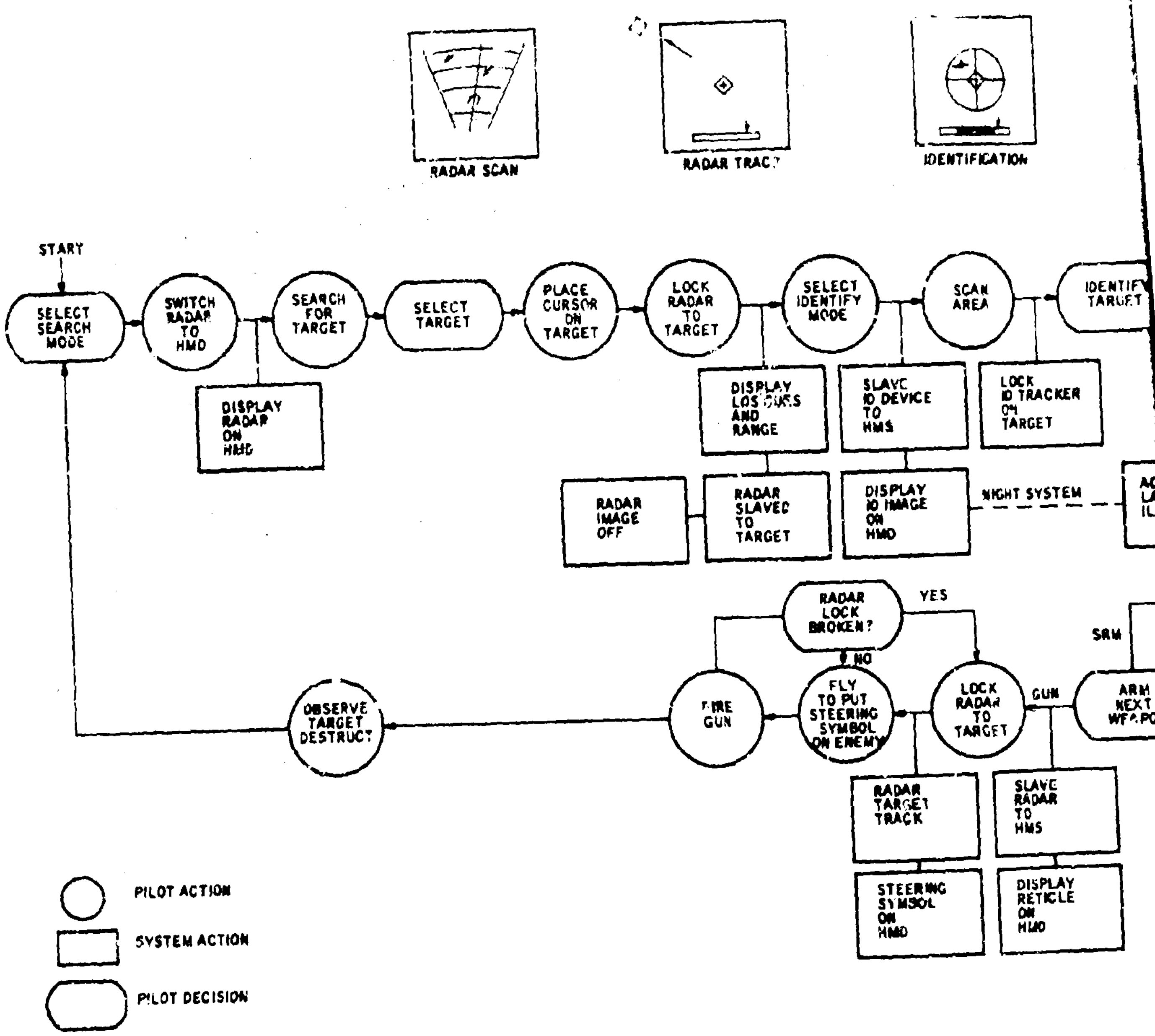
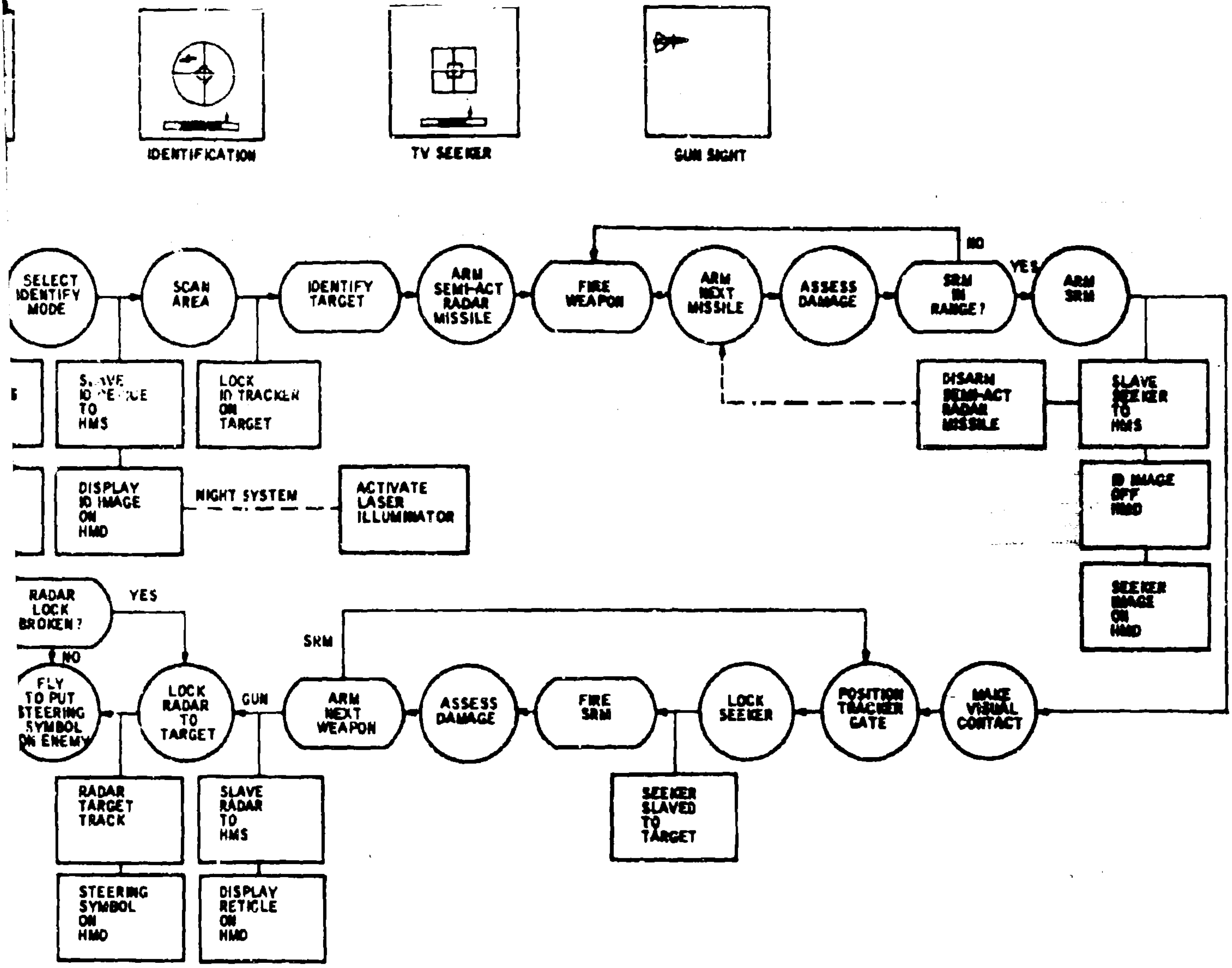


Figure 13. HMS/D Integration with Air-to

A



HMS/D Integration with Air-to-Air Combat Phase

B

Other potential display parameters such as altitude, airspeed, heading, IFF, target tracking data, attack warnings, and failure warnings are considered of interest to this phase but not fundamental to the basic role assumed by the HMS/D. In the interest of simplicity, these parameters are considered in the realm of add-on capability.

Air-to-air combat at night is assumed possible with the addition of a laser illuminator and a modified identification device. The feasibility of this approach has not been studied in depth so this is left as a possible concept for night identification and attack.

AIR-TO-GROUND COMBAT PHASE

In the air-to-ground combat phase, day operations and night operations are considered separately since different aircraft configurations are required. Night operations are considered of secondary importance and may not be applicable to the F-15.

Day Operations

The sequence of daytime air-to-ground attack is shown in Figure 14. Day operations do not include the use of radar tracking due to poor target resolution and heavy clutter. The identification tracker is assumed capable of tracking a ground target while range is derived from the radar by sampling along the boresight of the tracker. A laser range finder would provide more accurate data if one were available.

The weapons considered for attack include TV guided missiles, bombs, and a fixed gun. Upon weapon selection, the identification device imagery is automatically removed from the HMS/D and the appropriate weapon display appears. For missile selection, the seeker image appears along with a cue symbol indicating identification device direction. The symbol allows confirmation of tracking data and quick visual reacquisition. The missile's seeker is slaved to the pilot's LOS and is manually locked to the target. After lock the missile may be fired whenever range requirements are met.

Selection of bombs results in the presentation of an identification device tracking cue, a steering command as determined from the fire control solution, and a range-to-go display. The bombs may be released either automatically of manually consistant with present options. The steering command and range display appear fixed to the aircraft while the cue moves with the target.

Selection of the gun results in the display of a steering symbol which the pilot uses to point the aircraft to bring his gun to bear on the target.

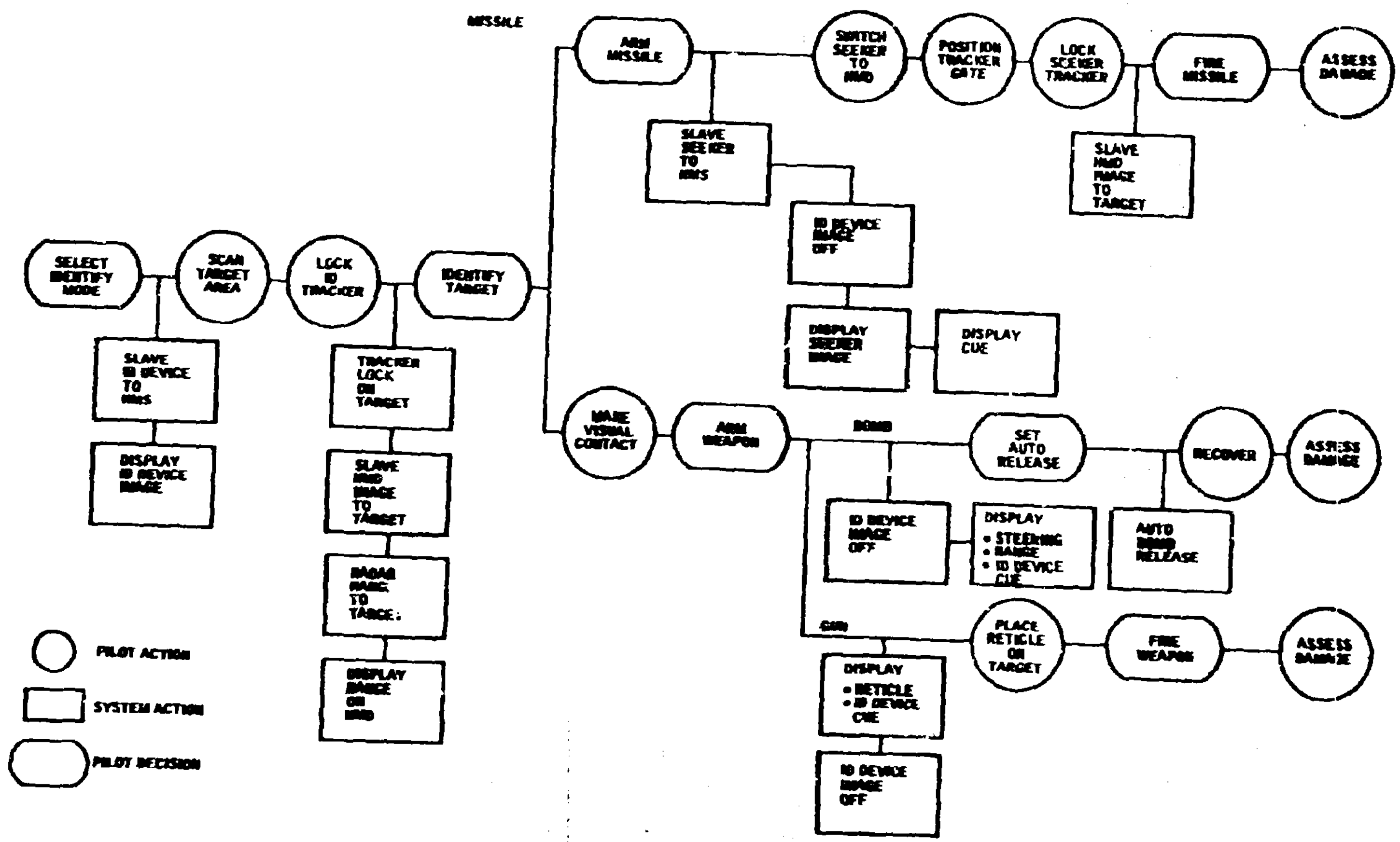


Figure 14. HMS/D Integration with Visual Air-to-Ground Combat Phase

Night Operations

Night air-to-ground combat assumes a different aircraft configuration in that the identification device function must be replaced by a high-resolution low-light-level sensor. A forward looking infrared unit (FLIR) was assumed for this purpose since it may be pod mounted and has extended capabilities over a low-light-level TV. Laser scanners were considered unavailable for pod mounting. A missile was also assumed developed for night air-to-ground combat which effectively utilize semi-active laser guidance. This requires a laser spotter to be held on target until termination.

The night operation sequence shown in Figure 15 is started with the radar in the ground map mode for long-range target localization. A position fix is obtained on a target area similar to the method of radar lock-on for air-to-air combat. In this case, a position fix is dead-reckoned inertially until the FLIR tracker may be locked on target. The FLIR mode is selected slaving the FLIR to the pilot's LOS and displaying its imagery on the helmet display. The cued target area is then scanned for a target, and the tracker is locked. Radar range is now sampled along the boresight of the FLIR, providing tracking data for a fire control solution. Selection of bombs or the fixed gun allows operation identical to day air-to-ground combat except that the FLIR image remains on the display after selection. The missile is fired after locking the seeker to a laser spot directed by the pilot's LOS.

In this case, the FLIR image is referenced to the target as before while the laser spot is referenced to the LOS. Missile guidance is similar to a semi-active radar guidance except that the spot is manually held on a target within the FLIR FOV. The state of development of such a weapon system is unknown at this time.

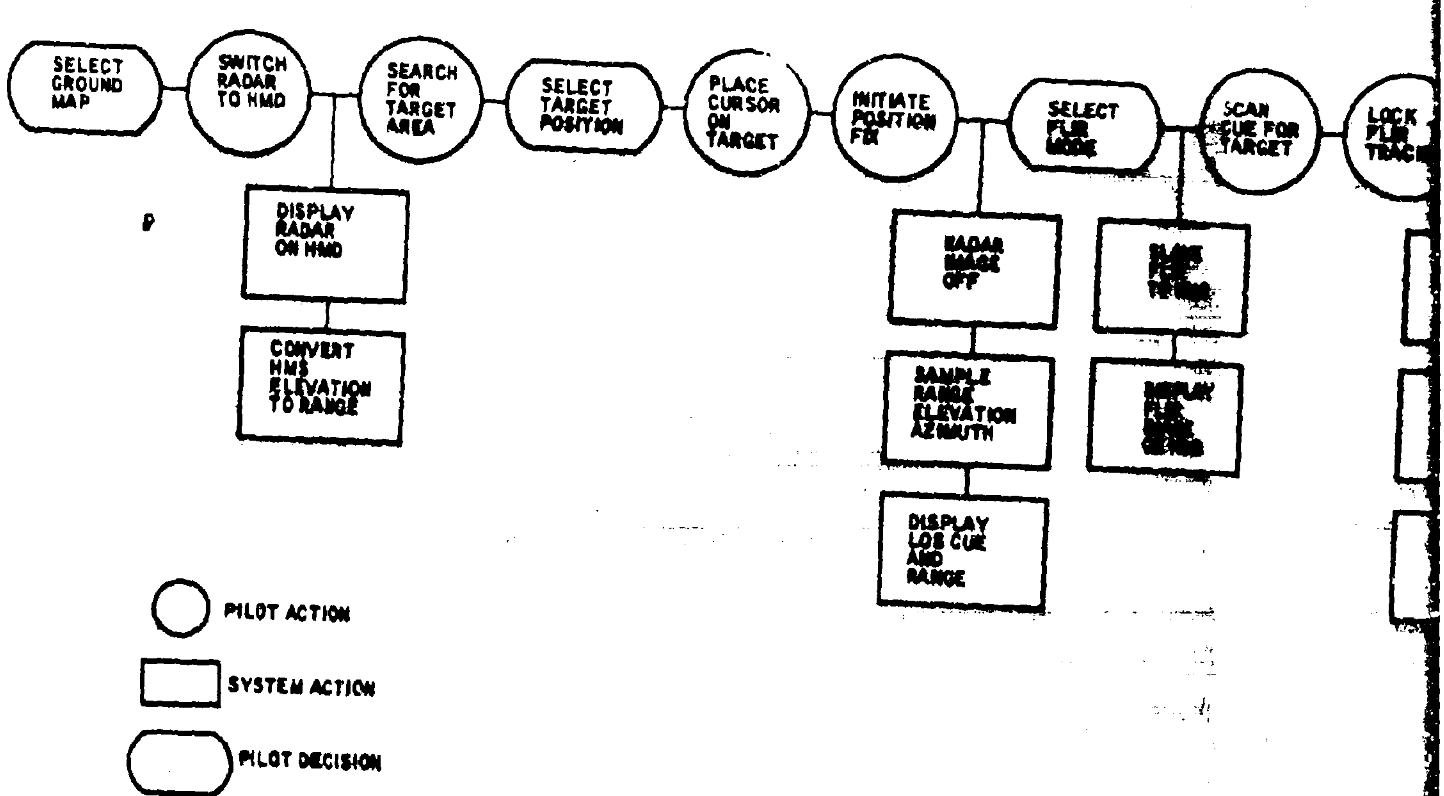
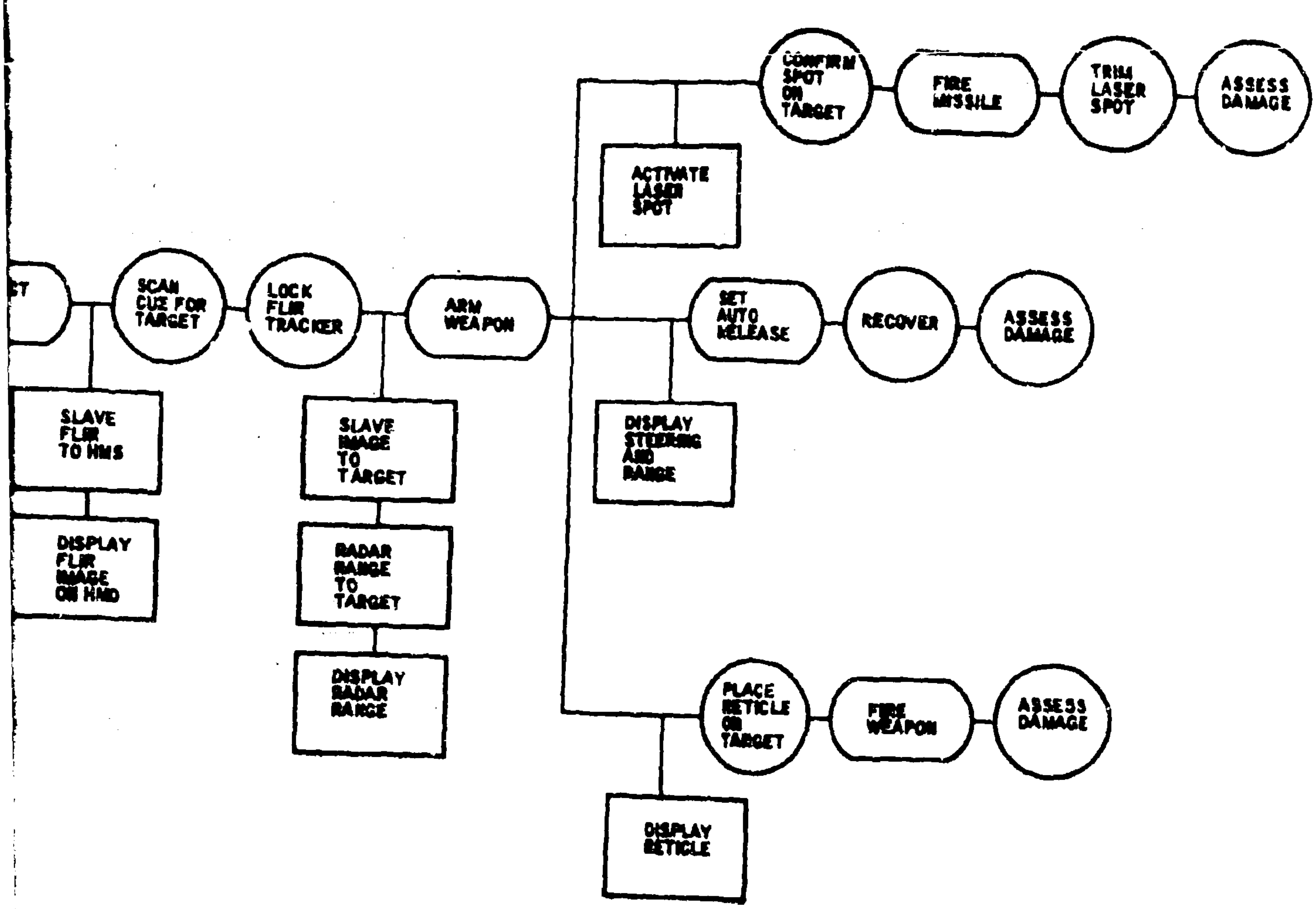


Figure 15. HMS/D Integration with Night A
Combat Phase

A



Integration with Night Air-to-Ground
Phase

B

SECTION IV
BASELINE DISPLAYS AND CONTROLS

This section analyzes and describes the use of the helmet-mounted sight and display subsystem from the operator's standpoint.

Although the HMS/D subsystem has many potential applications, the air-to-air combat application appears to offer the most complete sample of representative uses and will, therefore, be discussed in detail. By concentrating on a single phase of the F-15 mission profile, it is possible to specify more clearly the entire system capabilities in a concise and straightforward manner.

The following subjects are covered:

- Aiming symbols
- Display content and display position/movement
- Necessary controls
- Switching
- Operational sequence illustration

A primary objective of the analysis described in this section is to insure that the system is sufficiently flexible to permit the pilot to exercise decision making capability rather than be subject to arbitrary automatic sequencing of the HMS/D subsystem. Pilot decision override must be inherent in the system because no two missions are exactly alike.

In one case the pilot may be required to use medium-range missiles first. In another he may use fixed guns first. He may or may not receive long-range intruder warning, etc. These contingencies dictate a system which is versatile and adaptable to any given set of circumstances. This principle is applied in the following manner:

- First, the pilot can select any mode at any time without being required to sequence through any prior modes. For example, if the operator does not have the radar locked on any specific target and is faced with a close-range intruder without prior warning, he can immediately switch to either short-range missile or fixed gun and the subsystem will operate as intended. The system versatility allows the pilot to operate effectively in any type of closure/engagement situation.

- Second, the pilot has complete authority over the system in the matter of target selection. It will be noted that, in all lock-on sequences, the pilot accomplishes lock by aiming the sensor with head movement and by closing the acquisition switch. The lock-on could probably be made automatically without the acquisition switch, i.e., place gate over the target by head motion and tracker automatically locks. The acquisition switch is specified for two reasons:

  (1) If lock-on is automatic, the pilot may sweep his field of view across the wrong target or a friendly aircraft and accidently lock to it.

  (2) Since the radar or seeker is slaved to the helmet and doesn't lock until acquisition switch closure, the pilot has the capability to choose at the last moment a target different than the one he has been tracking during closure. Again - freedom of choice. He is not tied to any target just because the acquisition sequence was begun on it.

AIMING SYMBOLS

It is desirable to limit the number and types of symbols within the subsystem for two basic reasons. First, it is more economical to mechanize one or two standardized symbols. Second, and more critical, standardization of tracking symbols and display information symbology will increase the probability that the mission will be successful by providing the operator with an effective and versatile display format. Confusion and time delays are known to accompany the use of a large number of differing symbols requiring interpretation and/or integration.

The use of an HMS/D system in air-to-air combat is basic to five sighting/tracking functions within the mission definition of an advanced weapon system of the F-15 type. Specifically, the HMS/D system will be used to lock a long-range radar tracking system, to identify targets by means of a long-range electro-optical (E-O) identification device, to lock an E-O seeker for a short-range missile, to establish an accurate line of sight to a target, and to increase the accuracy of short-range gunnery. The above objectives could be accomplished through the use of three tracking symbols--a reticle a steering symbol and a tracking gate. Further discrete symbology may be employed as needed to provide secondary information to aid the operator in initially acquiring the target and to provide range/range rate information. The specific configuration of the symbols is left to future empirical investigations. For purposes of this report the tracking symbols shown in Figure 16 will be used.

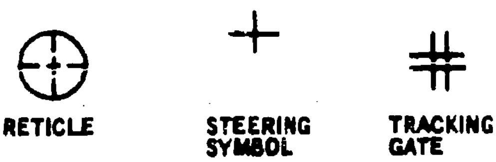


Figure 16. Reference Tracking Symbols

DISPLAY CONTENT AND DISPLAY POSITION/MOVEMENT

There are four possible alternatives of display position/movement:

- Fixed relative to aircraft axes: Data are translated in two axes on the helmet mounted display and are centered on the display only when the pilot is sighting along the fore-aft line of the aircraft.

- Fixed relative to aircraft axes except for displacement: Data are presented the same as in number one above except that they are displaced from the aircraft fore-aft axis to allow for lead computation, etc.

- Fixed relative to sensor pointing direction: Data are translated on the helmet mounted display and are centered on the display only when the pilot is sighting in the sensor pointing direction.

- Fixed relative to pilot's head: Data are not translated on the helmet mounted display; i.e., they appear in front of the pilot's eye no matter which direction he turns his head.

By using combinations of display elements positioned as above, display content and display position/movement for each sequential step of the HMD subsystem operation during air-to-air combat may be described. It should be emphasized that the sketches of displays contained in this section are representative formats. Final choice of displays will require further study.

Radar Search

During radar search, the entire radar plot is displayed and is fixed relative to the head. The presentation is the same in format as is normally

shown on a cockpit-mounted radar scope (see Figure 17). The display size is chosen to provide the required readability and will probably be such as to subtend an angle similar to that of present-day radar scopes. Extremely large display size is likely to be a distraction rather than an assistance to the radar search task since the time to scan the display with the eye may be extended if the display covers a very large angular range. During search, the radar scans in the azimuth direction and is controlled in elevation by a manual control. Elevation control could be given to the helmet sight, but this would impose a severe constraint on the pilot's head motion if he wishes to see a normal constant-elevation scan.

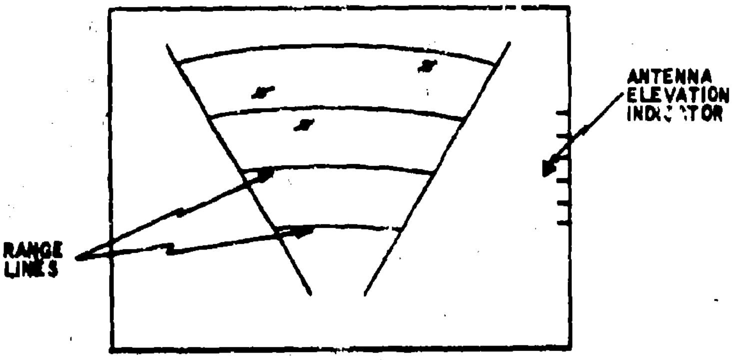


Figure 17. Radar Search Display

Radar Acquisition

Before radar lock takes place, the basic radar acquisition display from the radar scope is transferred directly to the helmet display (see Figure 18). The azimuth line and range gate are shown in the normal manner. The antenna elevation is controlled by a manual adjustment as before. The outputs of the azimuth and elevation channels of the helmet sight are used to control the azimuth pointing of the radar antenna and the position of the range gate respectively. The method of locking the radar to the target is the same as at present except that the lateral and fore-aft motions of the side-stick controller are replaced by the motion of the helmet sight. The

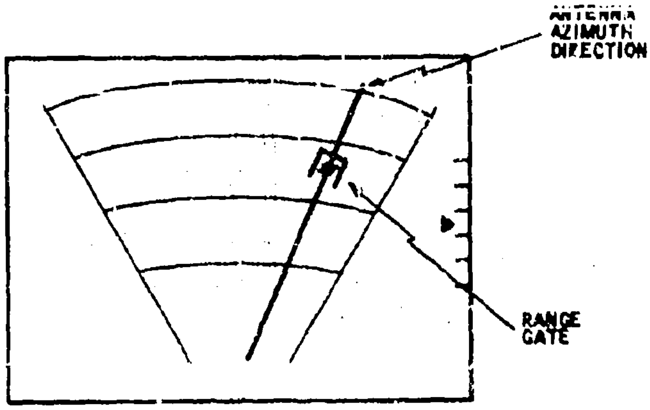


Figure 18. Radar Acquisition Display

pilot positions the radar antenna to illuminate the target and adjusts the range gate. The acquisition switch is then depressed to lock the radar. At the time of lock, control of the radar by the helmet sight is broken automatically.

The amount of head motion required to bring about the desired angular displacement of the azimuth line and the range gate is best determined by experimentation. One possibility is to have the pilot turn his head through angles which correspond to the desired angular motion on the display. This has the advantage of allowing the head to move through relatively small angles and of allowing him to predict directly the amount of motion that will be required. It has the disadvantage of requiring finer resolution and greater stability in the positioning of the head in order to bring about a lock. Another possibility is to require head motion in azimuth equal to the angle the real target is making with the aircraft axis and in elevation sufficient to be in proportion to azimuth motion. This has the advantage of putting the pilot's head in the proper azimuth position to see the target directly when it is in range, but the disadvantage of setting the head's elevation angle in an arbitrary direction which has no relation to the target's elevation angle. It also requires large head angles at a time when the pilot may prefer to be in close touch with his instrument panel and cockpit controls.

After successful lock-on has taken place, the display consists of a target symbol which is fixed relative to the radar pointing direction and a range display as shown in Figure 19(a). Since the symbol is fixed relative to the radar it is translated on the display as the pilot moves his head. By centering the symbol on the display, the pilot brings his line-of-sight to bear on the target.

If the pilot moves his head far enough to translate the target symbol off the display (i.e., looks away from the target) an arrow will appear, pointing in the direction the pilot must move his head to regain the target direction [see Figure 19(b)].

The arrow pointing direction is determined by pilot head/radar pointing relationship rather than aircraft/target relationships since the purpose of the cue is to tell the pilot where to move his head, not where to point his aircraft.

The range indicator shows radar range to the target and is fixed relative to the pilot's head, i.e., he sees it however he moves his head. A wide variety of indicators may be used. There are alphanumeric readouts, straight fixed scales with moving pointers, straight moving scales with fixed pointers, etc. For purposes of this discussion, a horizontal fixed scale with a moving pointer will be used, since it will not only give range information but will also give cues on closure rate. When a weapon is selected, the lethal range envelope for the weapons will be added to the range display.

Target Identification

This sequence also has two display modes; one during lock and the other after successful lock-on has taken place.

The first display mode consists of the identification device imagery overlayed with a tracking gate and the target range readout, and is fixed relative to the pilot's head [see Figure 20(a)]. The target symbol or cueing signal for radar direction is superimposed over the identification display and is still fixed relative to the radar pointing direction. This allows the pilot to place the tracking gate over the symbol (which points the sensor at the target) and initiate a tight scan around the symbol until TV, imagery of the target appears. The radar cues should be blanked at the center of the display in order to prevent a confusing "pile-up" of images in the tracker gate.

When successful lock-on occurs, the tracking gate disappears leaving only the tracker image and target symbol or cueing signal along with the range display [see Figure 20(b)]. The tracker image and range display are fixed relative to the pilot's head while the target symbol is fixed relative to radar pointing direction.

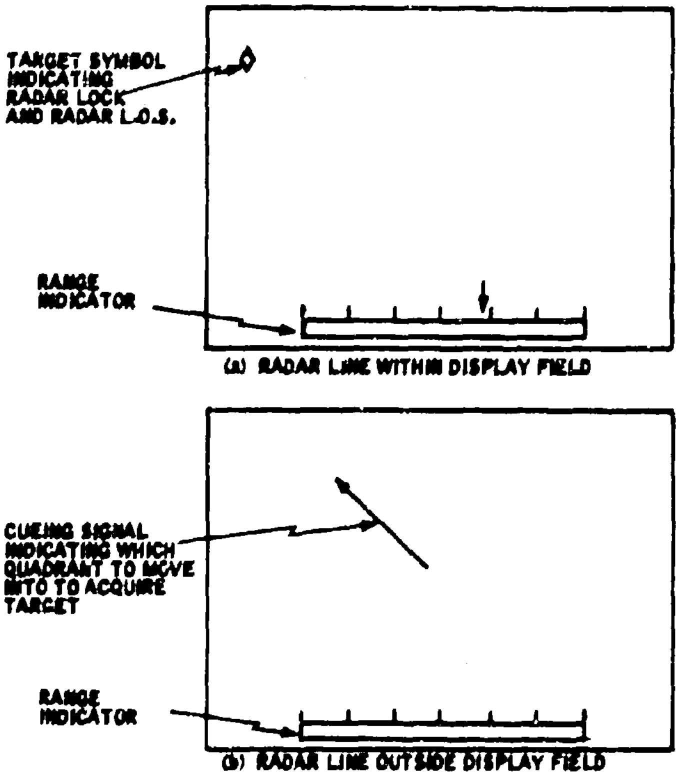


Figure 19. Radar-Generated Pointing Cues

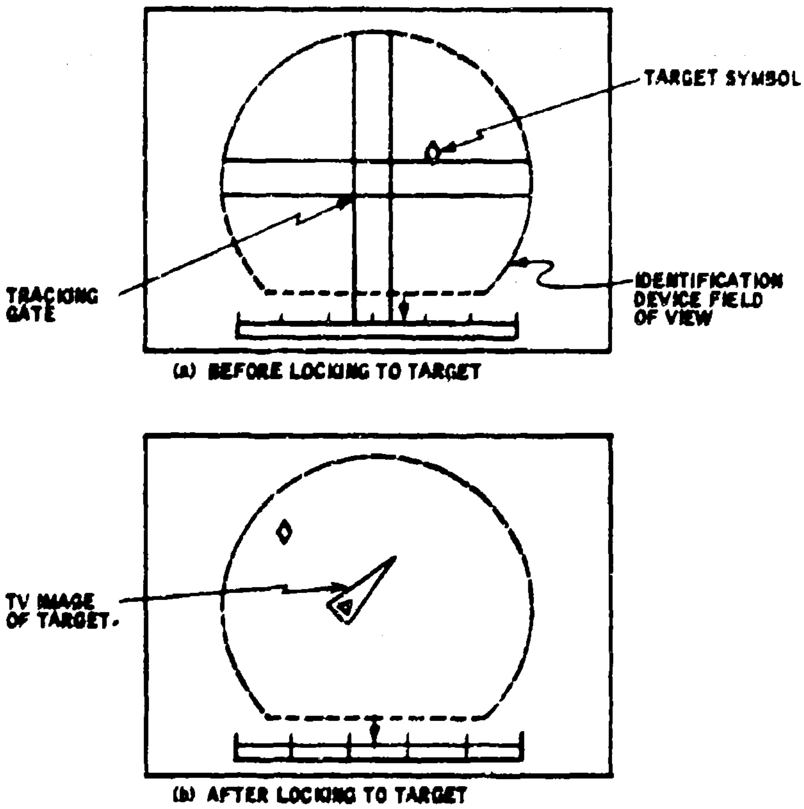


Figure 20. Target Identification Displays

Medium-Range Missile

When the MRM mode is selected, the identification device image is removed, a discrete signal appears indicating missile readiness and the lethal range envelope is added to the range display (see Figure 21). The discrete may be any symbol that is easily noticeable and identifiable. If at any time the radar breaks lock (thereby ceasing to illuminate the target) the target symbol/cueing signal and readiness discrete will disappear, allowing the pilot to drop back to radar mode and relock if he so desires.

Short-Range Missile

When the SRM mode is selected, the TV output of the missile seeker along with a tracking gate is displayed and is fixed relative to the pilot's head (see Figure 22). The range readout and target symbol/cueing signal are also displayed (indicating continuing radar lock and giving direction cues). The lethal range envelope for the short-range missile is presented on the range indicator. When successful missile lock is accomplished, all displays except the TV image and range readout disappear. These remaining displays are now fixed relative to the pilot's head. When the missile is fired, the TV image is removed, but the range readout remains as long as the radar remains locked.

A very definite advantage of this approach is that it gives the pilot the ability to actually "see through" the missile seeker thereby eliminating error due to wing flexure, boresight error, etc.

Fixed Gun

Selection of fixed guns removes all other imagery and displays a steering symbol which is fixed relative to the aircraft axes (translated on the display) except for displacement to allow for lead angle (see Figure 23). Position of the symbol relative to the armament datum line is determined by the fire control computation. The pilot flies the plane to place the symbol on the target aircraft seen through the display.

The computation of lead angle for the gunsight requires range data, thus requiring a radar lock. If the radar has been previously locked and remains so, the gunsight display appears immediately on selecting the guns mode. If the radar is not locked or comes unlocked during an engagement, one of two approaches to the problem may be taken. The fire control computation may insert a fixed range into the computation, in which case the attack may be carried on with an error in the aiming of the guns which will vary with the difference between the actual and the assumed range. As an alternative, the radar may be locked to the target again before proceeding with the attack. If the alternative is to be used, the radar lock must be made quickly and with a minimum of effort on the part

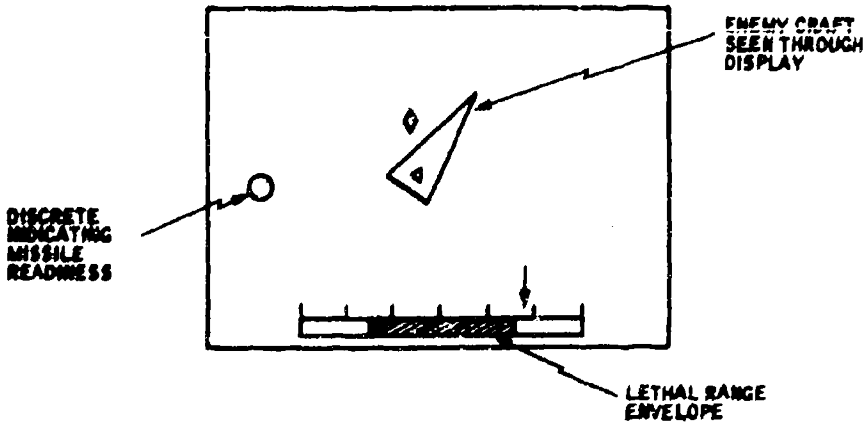


Figure 21. Medium-Range Missile Display

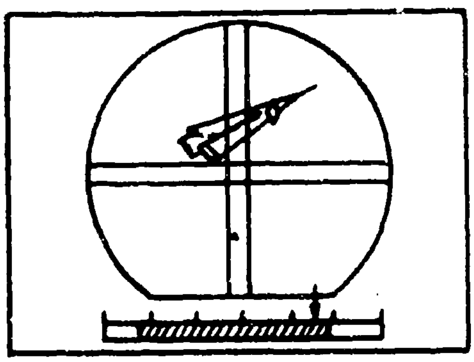


Figure 22. Short-Range Missile Display

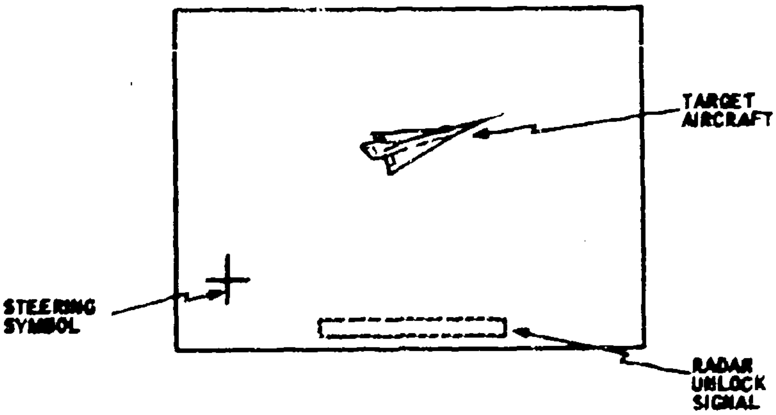


Figure 23. Gunsight Display

of the pilot. Since the enemy is likely to be at short range at this time, a locking method which slaves the radar pointing direction to the pilot's line of sight and utilized an automatically scanning range gate will be usable. To implement this, a sighting reticle to establish the line of sight is needed. Locking the radar should cause the fixed reticle for directing the radar to disappear and the steering symbol for the gunsight to reappear.

In the event of loss of radar lock during an actual gun attack, it is probably not desirable to have the steering symbol disappear automatically as an indication that the radar is relocked. Instead, a discrete warning of unlock would provide the pilot with the information needed and allow him the option of continuing the attack or of relocking the radar.

Priority Interrupts

A number of emergency situations may occur in the course of combat which should be called to the pilot's attention. These include fire warnings, low fuel supply, and other aircraft conditions which may affect the pilot's decisions. They also include warnings of attack from the rear which may be unnoticed otherwise. The outputs of radar receivers which indicate when the aircraft is being illuminated by an enemy radar or of sensors which indicate the appearance of enemy fighters or surface-to-air missiles may be displayed to alert the pilot of these conditions outside the aircraft.

The manner in which these interrupt displays are mechanized will depend on their urgency and on the activity under way at the time of occurrence. It will also depend on the wishes of the pilot himself. In a number of conversations fighter pilots have commented that once he is attacking an enemy the pilot does not want to have such warnings at all. Other comments have pointed to the desirability that such warnings not be interrupts, but rather be displayed in addition to and subsidiary to the weapon delivery displays already in use.

Because of the uncertainty of the degree to which such displays should interrupt others and the manner in which they should be presented, no formats for such warnings are given in this report.

NECESSARY CONTROLS

The following controls are required for the HMS/D subsystem:

- Power - two-position switch
- Mode - six-position rotary switch for air-to-air combat (additional positions may be needed for other applications):
  - Mode 1 - Radar search
  - Mode 2 - Radar acquisition
  - Mode 3 - Identification
  - Mode 4 - Medium-range missile
  - Mode 5 - Short-range missile
  - Mode 6 - Fixed gun
- Brightness - rotary adjustment (for nominal settings; brightness and contrast automatically adjusted to suit ambient conditions)
- Focus - rotating knob (protected)
- Astigmatism - rotating knob (protected)
- Vertical gain - rotating knob (protected)
- Horizontal centering - rotating knob (protected)
- Acquisition switch

In addition, the following display lights will be required:

- HMS/D power on
- HMS/D system ready

NOTE: A malfunction indicator may also be included.

The required controls should be in two locations which may be referred to as Panel "A" and Panel "B". Panel "A" (containing the mode control used during combat) is located on the side of the cockpit near the power controls and is accessible with a minimum amount of hand travel from throttle to mode control. Panel "B" (containing adjustment controls which are used primarily prior to flight) is located at any convenient point in the cockpit where it can easily be reached during boresight testing. Panel "B" should have some type of protective device to prevent accidental movement of the controls while at the same time leaving them easily adjustable.

In summary, note that all adjustments and tests can be made prior to take-off, necessitating the use of only the mode switch on Panel "A" during flight. The only other HMS/D control switch used during flight is the acquisition switch.

SWITCHING

One prime consideration in the switching problem is to give the pilot capability to do as much of the necessary switching as possible without looking down into the cockpit. Another prime consideration is the number of additional switches required for the HMS/D subsystem. A cursory examination of any modern day aircraft cockpit will quickly reveal that in many instances the pilot is already seriously overloaded.

Only two HMS/D subsystem switches are required to be used during engagement--the mode switch and acquisition switch.

Mode Switch

Specific modes or submodes of the HMS/D subsystem are in parallel with and serve certain weapons modes. One approach then, is to have the HMS/D submodes or sequences initiated by the weapon selection switch on the ordnance panel. This approach has a distinct disadvantage, though, in that it requires the pilot to look down into the cockpit each time he selects a weapon.

An alternative and seemingly more attractive approach is to have weapon selection controlled by HMS/D mode switching. This alternative has the following advantages:

- A sharply detented rotary mode switch can be set without looking down into the cockpit. Positive indication of weapon mode selected will be given by display format.

- HMS/D mode selection and weapon selection are accomplished by the same switch, thereby reducing the number of separate switches which must be operated during the combat engagements.

Seven HMS/D subsystem modes are required for air-to-air combat. These are:

- Radar search
- Radar acquisition
- Identify
- Medium-range missile
- Quick radar lock
- Short-range missile
- Fixed gun

Acquisition Switch

The acquisition switch should be located either on the control stick or on the throttle. Either of these positions allows the use of the acquisition control by feel instead of by visual location. A third possible location, which is only slightly disadvantageous, is adjacent to the radar antenna elevation control. If the elevation control is properly located and suitably shaped to assure proper operation without visual effort, the acquisition switch may be located with it. Since the acquisition switch replaces the radar lock control, its location with the other radar control would be in line with present practice.

The normal sequence of control operation for any of the HMS/D modes is generally as follows:

(1) Select mode
(2) Point sensor
(3) Operate acquisition switch
(4) Operate firing trigger (weapon delivery modes)

This sequence is examined in more detail in the following paragraphs.

OPERATIONAL SEQUENCE ILLUSTRATION

The following procedures summarize and link together the descriptions of system operation in the preceding paragraphs:

- As the pilot approaches the combat area, or at any time he so chooses, he sets the HMS/D mode switch to "Search". This displays the radar plot on helmet display thereby allowing him to search for target returns without looking down into the cockpit.

- When the pilot decides to lock the radar to a target, he switches to "Radar Acquisition" mode, places the range gate over the target, and presses the acquisition switch. Successful lock is indicated by appearance of the "radar lock" display format which includes range data.

- As closure continues, the pilot selects the "Identify" mode. This causes the identification device to slave to his sight line and displays the TV output along with a tracking gate and target symbol. The pilot initiates a tight scan about the target symbol until target image appears on the display. Depression of the acquisition switch then causes the tracker to lock. Successful lock is indicated by disappearance of the tracking gate and appearance of range data (the latter assumes that the radar is still locked). The image is now fixed relative to the pilot's head, allowing him to continue monitoring the target while doing other tasks.

- When appropriate range is reached, the pilot selects "MRM" mode. This automatically activates the appropriate medium-range missile. The display remains the same except that a discrete appears indicating missile readiness and the missile's lethal range envelope is added to the range display. The pilot then releases the missile by depressing the trigger. The system automatically sequences to the next medium-range missile, and the pilot monitors hit or miss either directly or on the identification device.

- Assuming misses and continued closure, the pilot then selects the "SRM" mode. This automatically activates the first short-range missile, places its seeker output and a tracking gate on the helmet display, and slaves the missile seeker to the pilot's sight line. The pilot then locks the seeker to the target by placing the tracking gate over the target and depressing the acquisition switch. Successful lock is indicated by disappearance of the tracking gate and appearance of the range data. The pilot then releases the missile by depressing the trigger switch. When the missile is fired, the system automatically sequences to the next short-range missile, and the SRM sequence restarts.

- As closure continues, the pilot selects the "Guns" mode. This arms the cannon and places the steering symbol on the helmet display. The symbol is fixed relative to the aircraft axes except for lead angle displacement. The cannon is fired by depressing the trigger switch when the plane has been maneuvered to place the steering symbol on the target.

The idealized sequence of air-to-air combat described above is illustrated in flow chart form in Figure 24. Also shown in the flow chart are a few of the alternatives which may be used. In addition to the alternative sequences shown in the chart, the use of the HMS/D (and the armament it controls) may be initiated at the head of any column on the flow chart and may sequence in any order. The control method chosen appears to offer great flexibility and great simplicity at the same time. The HMS/D mode control is the only "new" control added to the cockpit since the acquisition switch replaces the radar lock control, and the firing switch is a part of the cockpit already. In terms of controls used during the combat engagement, the mode control represents a reduction in controls rather than an addition because it replaces the selection switches for the various weapons used. Similarly, the acquisition switch replaces not only the radar lock control but also similar controls in the identification subsystem and the missile control subsystem. Thus, the overall result of the use of the control system is a reduction in the number of switches which must be used during combat.

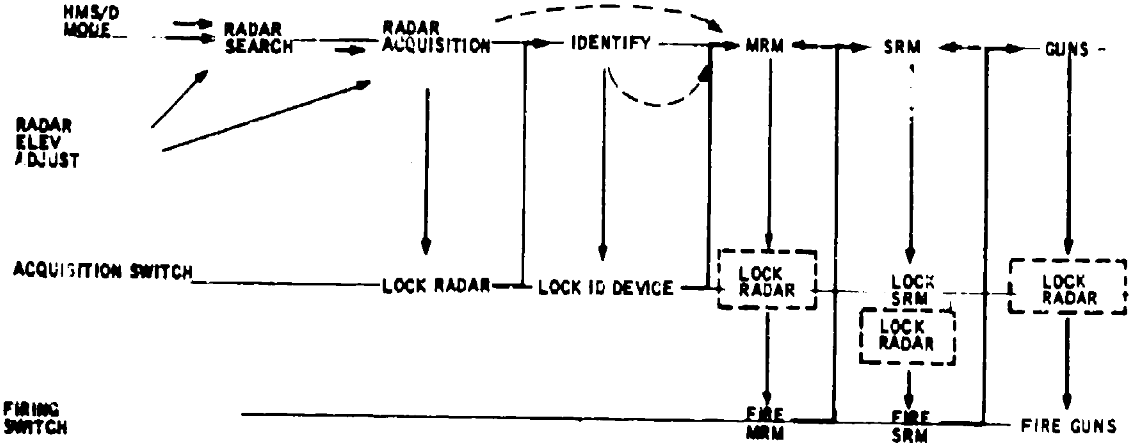


Figure 24. Flow Chart of Idealized Air-to-Air Combat Sequence

SECTION V

HMS/D - SENSOR INTERFACES

SENSOR COMPLEMENT

The instrumentation on the F-15 is likely to be highly restrictive from the standpoint of weight, space, and the drag of protruding objects such as lenses and antenne housings. With the selection of sensors being somewhat rigid and the number small, it is clear that any HMS/D application having unusual requirements in space, weight, or external mountings will be difficult to implement. The sensors likely to be included on the F-15 and the application areas for the HMS/D related to those sensors are as follows:

- Radar - A high-performance radar is likely to have top priority. The dish antenna location in the nose occupies the premium space for sensors on a high-performance fighter. The antenna dish is a yard or so in diameter, and it must be deflected ±60 degrees so the nose cone of the aircraft can be regarded as being totally allocated. The radar will be the main "eye" of the whole system, whether for search, attack, or navigation.

- Passive Radar Receiver - A broad-band receiver responds to radar pulses emanating from remote sources. The intent is to alert the pilot to the possibility that he is being tracked by radar. The unit should provide directional information at least to the extent that the quadrant is indicated.

- Rear Warning Device (IR) - A rearward looking, IR scanner detects missiles or aircraft approaching from the rear sector. It can indicate the presence of several missiles or aircraft, within its cone of sensitivity.

- Long-Range Identification Device - The long-range identification device consists of a telescope with a vidicon pickup tube and remote CRT display. It is particularly suited to the helmet display. The device is not yet operational, particularly for a single-place aircraft. However, it should be possible to satisfy this requirement, and, if it has an automatic tracking capability, it should be particularly useful on the single-place F-15. It will probably be a part of the sensor complement because it is the only reliable means for visual identification of aircraft which are beyond range for direct view with the unaided eye. It is probably limited to daytime use though it might be extended into low-light-level uses.

- Radio Receivers - Several types of radio receivers can be expected on the F-15. These include voice communications, data link, and automatic direction finding (navigation). There are also transmitting units associated with both the voice communications and the data link.

- Missile Seekers - The homing devices which can be expected on missile heads are infrared, electro-optical, radar, and semi-active radar. Provision for at least two of these will likely be made. While these missile sensors are not part of the actual aircraft, they must be treated as such because, during the pre-release state, they are linked with the HMS/D and/or the radar.

This completes the tentative list of sensors which are expected to be of importance to the HMS/D applications which are external to the aircraft. Any proposed uses of the HMS/D must deal with this list.

Some comments should be made about sensing systems which are not included in this list. The laser scanner, FLIR, direct view image intensifier, and LLLTV are devices to be used for night operations, particularly against ground targets. Their sizes,weights and particularly their massive optics probably prevent their addition to an already-loaded F-15. If these sensors are eliminated, night combat operations for the F-15 seem to be precluded. Positive recognition presently must be obtained before releasing an air-to-air weapon. This is done in daylight by direct view or, at longer range, by using the TV identification device. With IFF being an unreliable guide, recognition at night is difficult since a night identification device, which is merely a LLLTV, cannot provide great range without a massive optical system with an aperture that would rival that of the primary radar. Air-to-air operations at night may be possible if a workable laser illuminator becomes available. Such an illuminator, operating in the wavelength range of sensitivity of the identification device, having a beam divergence of up to 1 degree, could make night identification possible. The optical aperture size would allow the illuminator to be located in the leading edge of the wing or at the wing top.

Figure 25 is a schematic diagram of the aircraft with the locations of the proposed sensors shown. HMS/D applications must be based on potentially useful linkages among sensors and between HMS/D and sensors. These linkages are summarized in Table II.

The internal uses of the HMS/D refer mainly to the display portion of the helmet assembly. Cockpit uses of the sighting portion of the assembly have been proposed in connection with a somewhat radical type of cockpit management, but this is likely to be well beyond the state-of-the-art applied to the F-15. The internal uses of the display portion of the helmet assembly include such things as fuel management, navigation data and general aircraft status indications. These comprise a category of functions which, by itself,

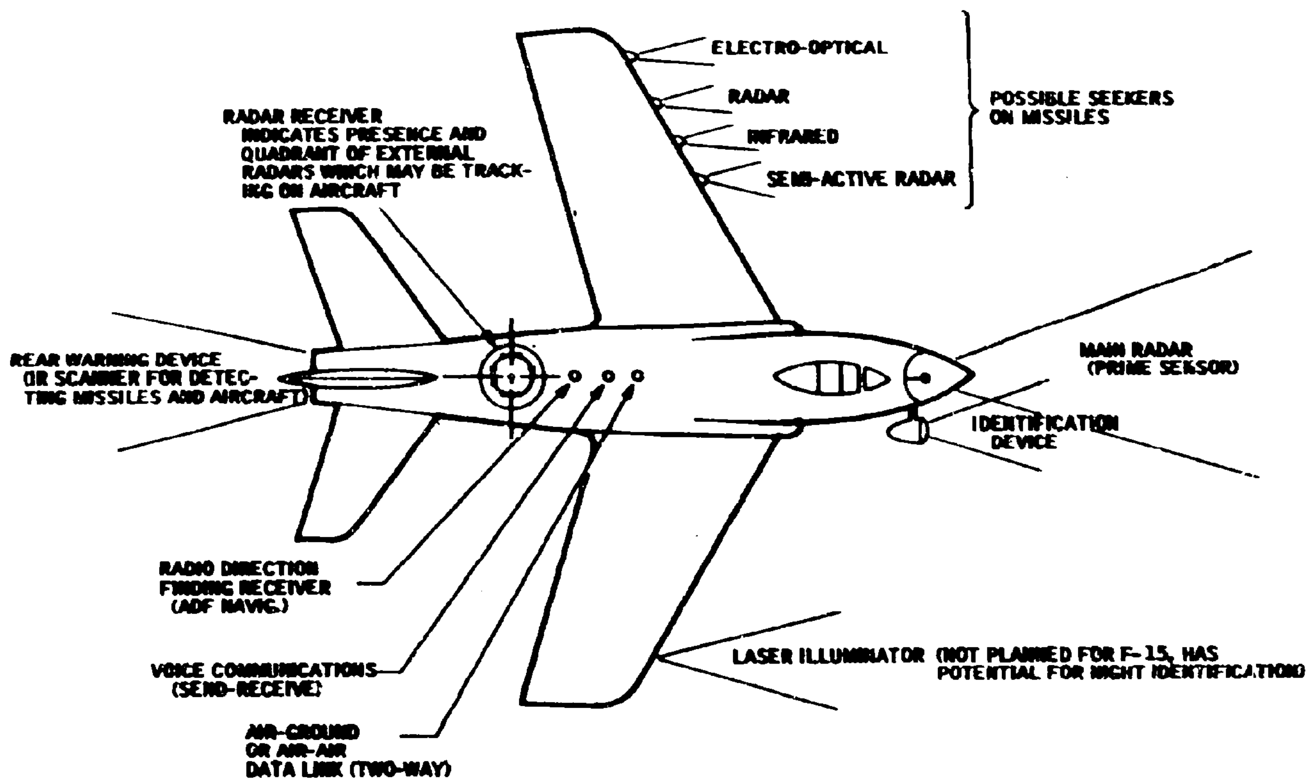


Figure 25. Sensor Complement on F-15 Aircraft

Table II. Relationships Among F-15 Sensors

	Controlled Unit / Controlling or "feeding" Unit	(1) Helmet Sight (HMS)	(2) Helmet Display	(3) Main Radar	(4) Identification Device	(5) Laser Illuminator	(6) Missile Seekers (on missile heads)	(7) Rear Warning (IR Scanner)	(8)
(1)	Helmet Sight (HMS)		Permanently linked by structure; display screen always co-directional with line of sight. (1) (2)	Important application Means for directing radar at one of a cluttered group of targets which are visible to pilot (1) (2)	Important application Means for directing at visible target for inspection under magnification (1) (4)	No application Helmet sight - illuminator link probably superfluous (1) (5)	Prime application Fast means for directing missile seeker to visible target (1) (6)	No application (1) (7)	No [illegible]
(2)	Helmet Display	See (1) (2) Floating display on helmet useful for directing pilots head to a particular target in display. See radar application (3) (1) below							
(3)	Main Radar Main sensor on aircraft; occupies "premium" space in nose cone	Special application Main radar display on helmet used for directing pilots head toward target selected from radar display field; before lock-on; may be in advance of visual detection of target. (3) (1)	Important application Main radar display transferable to helmet-mounted CRT (3) (2)		Important application Main radar servos ID Device (3) (4)	Alternative application Laser illuminator normally servoed by ID [see (4)(5)] but may be served directly by radar. (3) (5)	Prime application Main radar servos missile seekers; for case when lock-on is to occur before release. (3) (6)	No application Rear warning field generally opposite main radar field. (3) (7)	[illegible]
(4)	Identification Device Electro-Optical telescope; Optics + Vidicon + CRT. Required for long range I.D. in daytime air-to-air operations		Important application ID imagery transferable to helmet mounted CRT (4) (2)	No application No purpose in having ID servo main radar		Important application ID servos illuminator for night visual ident. [illegible] reaching radar [illegible] See (3)(5) for al[illegible] mate drive (4) (5)	Unlikely application Missile seekers normally servoed by main radar [(3)(6)] Possible application in event of radar failure (4) (6)	No application Rear warning field generally opposite ID field. (4) (7)	[illegible]
(5)	Laser Illuminator Visual or near IR Laser; instantaneous field and direction coincides with I.D. device. This device not planned but required for night air to air operations.		No application (5) (2)	No application (5) (3)	No application (5) (4)		No application Seekers normally servoed to main radar and possibly to ID Device (5) (6)	No application Rear warning field generally opposite illuminator field (5) (7)	[illegible]
(6)	Missile Seekers (on missile heads) 1. Electro-optical 2. Infrared 3. Radar 4. Semi-active radar		Important application Seeker "view" transferable to helmet mounted CRT	No application No purpose in seekers servoing main radar. See reverse application [(3) (6)] (6) (3)	Possible application May be desirable to view target that missile is locked into (6) (4)	No application (6) (5)		No application Rear warning field generally opposite seeker fields (6) (7)	[illegible]
(7)	Rear Warning (IR scanner) detects and indicates directions to missiles or aircrafts within fixed rear cone of sensitivity		Important application Low key display until threat approaches high level. Possible use of audio supplement [see (7) (9)] (7) (2)	No application Fields generally opposite (7) (3)	No application Fields generally opposite. (7) (4)	No application Fields generally opposite. (7) (5)	No application Fields generally opposite (7) (6)		[illegible]
(8)	Radar Receiver Broadband receiver detects remote radars beaming at aircraft; quadrant indicating.		Important application Low key display until threat approaches high level. Possible use of audio supplement see [(8) (9)] (8) (2)	No application Related when source is ahead of aircraft, but no need for linkage (8) (3)	No application (8) (4)	No application (8) (5)	No application (8) (6)	No application Related when source is behind aircraft but no linkage required (8) (7)	
(9)	Voice Communication (two-way) UHF Secure (voice scrambling and unscrambling)		No application (9) (1)	No application (9) (3)	No application (9) (4)	No application (9) (5)	No application (9) (6)	No application (9) (7)	[illegible]
(10)	Air Ground or Air-Air UHF data link (two-way)		No application (10) (2)	No application Possible use in having control of main radar from remote (air-to-ground) station. Not proposed at this time (10) (3)	No application (10) (4)	No application (10) (5)	No application Possible use in directing missile seekers from remote air or ground station. Considered unlikely at this time. (10) (6)	No application (10) (7)	[illegible]
(11)	Radio Direction Finder (ADF navig.)		Minor application Useful to display ADF homing data; not important to air-to-air operations. (11) (2)	Possible application May be desirable to direct radar to radio direction finding source esp. for air-to-ground combat operations. (11) (3)	No application (11) (4)	No application (11) (5)	No application (11) (6)	No application (11) (7)	[illegible]

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Table II. Relationships Among F-15 Sensors

(4) Identification Device	(5) Laser Illuminator	(6) Missile Seekers (on missile heads)	(7) Rear Warning (IR Scanner)	(8) Radar Receiver	(9) Voice Communications (two-way)	(10) Air-Ground or Air-Air Data Link (two-way)	(11) Radio Direction Finder (ADF Navig.)
Important application. Means for directing at visible target for inspection under magnification (1) (4)	No application. Helmet sight* illuminator link probably superfluous (1) (5)	Prime application. Fast means for directing missile seeker to visible target (1) (6)	No application (1) (7)	No application (1) (8)	No application (1) (10)	No application (1) (10)	Possible application - May be useful to direct ADF beam to visible ground station. Not imp. in air-to-air operations. (1) (11)
Important application. Main radar servos ID Device (3) (4)	Alternative application. Laser illuminator normally servoed by ID [see(4)(5)] but may be served directly by radar (3) (5)	Prime application. Main radar servos missile seekers; for case when lock-on is to occur before release. (3) (6)	No application. Rear warning field generally opposite main radar field. (3) (7)	No application. Radar receiver assumed to provide only rough indication of direction to source. (3) (8)	No application (3) (9)	Some application. Radar data telemetered to air or ground station; usually via computer; most useful for air-to-ground tactics. Usefulness in air-to-air questionable (3) (10)	No application. Relationship between nav. radar and radio direction finding sources but no need for linkage (3) (11)
	Important application. ID servos illuminator for night visual ident. of approaching radar target. See (3)(5) for alternate drive. (4) (5)	Unlikely application. Missile seekers normally servoed by main radar [(3)(6)] Possible application in event of radar failure (4) (6)	No application. Rear warning field generally opposite ID field. (4) (7)	No application. Radar receiver assumed to provide only rough indication of direction. (4) (8)	No application (4) (9)	Possible application. ID video may be placed on data link for remote display. Most useful for air-to-grnd. combat op's (4) (10)	No application (4) (11)
No application (5) (4)		No application. Seekers normally servoed to main radar and possibly to ID Device (5) (6)	No application. Rear warning field generally opposite illuminator field (5) (7)	No application (5) (8)	No application (5) (9)	No application (5) (10)	No application (5) (11)
Possible application. May be desirable to view target that missile is locked into (6) (4)	No application (6) (5)		No application. Rear warning field generally opposite seeker fields (6) (7)	No applications (6) (8)	No application (6) (9)	Possible appl. Seeker vdo. & prog. signals may be plcd. on data lnk for remt stn. Most usfl for air-to-grnd. combat ops. (6) (10)	No application (6) (11)
No application. Fields generally opposite. (7) (4)	No application. Fields generally opposite. (7) (5)	No application. Fields generally opposite. (7) (6)		No application. Related when source is behind aircraft but no linkage required (7) (8)	Important application. Supplementary audio alert from rear warning device (7) (9)	No application. Possible uses in placing output of rear warning device on data link. Not propsd at this time (7) (10)	No application (7) (11)
No application (8) (4)	No application (8) (5)	No application (8) (6)	No application. Related when source is behind aircraft but no linkage required (8) (7)		Important application. Supplementary audio alert from rear warning device (8) (9)	No application. Possible uses in placing output of radar receiver on data link. Not proposed at this time. (8) (10)	No application (8) (11)
No application (9) (4)	No application (9) (5)	No application (9) (6)	No application (9) (7)	No application (9) (8)		No application. Poss. uses in placing voice comm. on data link; problem in digitizing; not propsd. at this time (9) (10)	Possible application (9) (11)
No application (10) (4)	No application (10) (5)	No application. Possible use in directing missile seekers from remote air or ground station. Considered unlikely at this time (10) (6)	No application (10) (7)	No application (10) (8)	Possible application. Data from remote air or Ground station may be required in voice com. channeled via data link. Esp. for air to ground combat operations. (10) (9)		No application (10) (11)
No application (11) (4)	No application (11) (5)	No application (11) (6)	No application (11) (7)	No application (11) (8)	No application (11) (9)	No application (11) (11)	

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cannot justify the use of the HMS/D. Such supplementary uses of the HMS/D may be added when air superiority applications have been completely implemented.

SENSOR INTERACTION

To evaluate the use of the HMS/D, it is necessary to examine the potential interactions between the various sensors and between the sensors and the HMS/D. Table II offers a convenient tool for this examination. All of the sensors are listed vertically, with basic descriptions, and all are relisted horizontally. The common areas in the intersecting columns and rows represent linkages between pairs. Owing to the double listing of sensors, there are actually two common areas for each pairing. This is useful for expressing the concept of "flow" from one element to another. For example, the main radar controlling the identification device is represented on the chart by space (3) (4), and the identification device driving the main radar is represented by space (4) (3) (the number from the vertical listing is given first). Many pairs are meaningless or have no application. If the night laser illuminator is not applicable, column and row 5 must be deleted. It is emphasized that Table II is used for citing uses of linked pairs of sensors; a consistent "no application" listing does not reflect on the usefulness or importance of the sensor itself.

The first use of the Table II is to cite the useful linkages for the air-to-air problem without the HMS/D. The useful linkages are important but very few in number. As expected, the radar plays the primary role.

Main radar (3) ⟶ Identification device (4); important application

Main radar (3) ⟶ Missile seekers (6); important application

Identification device (4) ⟶ Laser illuminator (5); important for night operations if illuminator is available

Identification device (4) ⟶ Missile seekers (6); as alternative to radar ⟶ seekers

No other major linkages can be sited for air-to-air operations. Other devices shown on the table are of importance to the air-to-air problem but they are not linked to other devices except through the deliberate actions of the pilot. Devices which have outputs presented to the pilot for interpretation (audio or visual) are:

Main radar (3) ⟶ Displayed to pilot (CRT)

Identification device (4) ⟶ Displayed to pilot (CRT)

Missile seekers (6) ⟶ Lock-on and homing information display to pilot

Rear Warning (7) → Displayed to pilot (CRT, audio, other visual)

Radar receiver → Displayed to pilot (sector indicator)

Voice communications (9) → Audio to and from pilot

This latter list represents a significant number of items which terminate at the pilot and which must attract his attention. These will often require his interpretation and reaction. The pilot must also monitor and interpret the various demands of aircraft management including altitude, fuel, g-loading, fire indications, and mach number. Some of these may be de-emphasized during combat but they can never be totally ignored. Beyond all this, the pilot must devote close visual attention to the external scene in all visible sectors. In fact, the transparent canopy comprises a visual "display" which is often overlooked in analytical work and which demands the greatest share of the pilot's visual attention during close air-to-air combat. These two "display" categories expand the number of general monitoring requirements to eight.

The general air-to-air activity, without the HMS/D, is summarized below (it is assumed that the combat phase is imminent):

- The main attention is centered on the search radar.
- Radar targets are identified at the extreme range of the identification device.
- Missile seekers or flexible guns are trained on identified targets by commands from the radar or identification device. If fixed guns are used, the aircraft is "trained" on target.
- Weapons are fired.
- Concurrent defensive and aircraft management activities are carried out.

Two important processes in this sequence are automatic; the radar-to-identification-device link and the radar-to-weapon link. At the same time, there are eight open-end items which terminate at the pilot, one or all of which may be clamoring for the attention-interpretation-reaction sequence.

This is a highly abbreviated account of the pilot's air-to-air combat duties, but it is sufficient to cite the main problem area. The pilot is generally overloaded during the demanding periods of air-to-air combat. One solution to this problem is to provide automatic linkages which relieve the pilot of as many functions as possible. The radar-to-weapon servo is an example of

such a linkage, though it does not entirely succeed. The radar display is such that the lock-on still requires some manual confirmation, particularly if other aircraft are present.

The general problem is known to be one of excessive monitoring and manipulating loads for the pilot during times of intensive involvement with aircraft operations. The HMS/D, to be useful, must be capable of alleviating rather than complicating this problem. The eight attention-demanding items cited above were regarded as terminating "open end" at the pilot. Combinations of these often require simultaneous monitoring, leading to simultaneous interpretation and reaction requirements. Three approaches can be considered as possible remedies:

- Additional system linkages for automatic monitoring, interpretation, and response to emergency situations
- Reduction in the number of inputs requiring monitoring interpretation and response
- More efficient use of the perceptive and manipulative powers of the pilot

Additional automatic linkages seem promising until the low confidence in a machine's ability to recognize crises is considered. There are even deeper reservations concerning the machine's ability to rate crises to the extent that priority reactions are accomplished. The IFF system is an example of a potential decision maker which is not trusted, machine failures being possible on either aircraft and innocent "non-target" aircraft not equipped with IFF transponders being present. Even when operating with reliable inputs, the machine's critical decisions must be reviewed by the pilot. In this process, the time saving which served as the original basis for the automation, is often lost.

The rear warning indicator is an important example of a sensor which terminates at the pilot. This sensor can present information which requires a quick judgment on whether to continue an attack or to break off and commence evasive maneuvers. The machine that can properly make this decision, including a judgment on the time and manner of break-off, is not forecast for the 1975 era. It seems clear that the critical sensor-man interfaces cannot be eliminated by automation.

Regarding the second approach to easing the pilot's lot, the number of inputs requiring pilot monitoring, interpretation, and reaction will probably not be reduced. Displays can be consolidated and can be made more efficient, but the general sensor-man interfaces will remain for the 1975 era. In fact, as aircraft improve, it will take effort to prevent the number of such inputs from increasing.

The remaining remedy is to make more efficient use of the pilot's perceptive and manipulative powers. The two human senses of greatest concern are visual and aural, and, in this context, a set of headphones may be considered as a "display". Audio warnings, superimposed on the voice communication channels, are a known and utilized means for alerting the pilot to special situations. At present, there is a great amount of aural information passed to the pilot via radio communication and intercom talk. Additional signals via aural inputs seems a doubful approach. With the audio loaded to capacity, there remains a high number of visual interfaces clamoring for pilot attention. These visual interfaces can be placed in two general categories:

- Displays which are normally "look-down" and include the main radar, identification device, missile seekers, rear warning, radar warning receiver, and those aircraft status indicators which are important during air-to-air combat.
- The "look-up" display which is simply the view through the transparent canopy; it occupies by far the larger portion of the pilot's attention during combat.

Since the number of displayed functions is high but irreducible, the improvement must be found in the minimizing of the look-down/look-up conflict. Time loss in the transfer and reorientation process is important, but the main danger is in the occurrence of rapid developments in the unwatched domain. The advantage of the audio monitoring is that the signal gains attention regardless of where the pilot is directing his visual attention. The helmet display offers the same advantage. Critical developments, normally displayed on look-down devices, gain the pilot's attention while he is occupied with the external view.

The helmet sight also assists in the easing of pilot work load by providing control inputs without requiring use of hand or foot motion. The helmet sight, servoing the missile seeker or identification device, offers simultaneous weapon training and target confirmation. The target selection is fast, certain, and most particularly it is direct.

The following statements summarize the sensor/HMS/D relationship:

- The pilot is overloaded at critical times during air-to-air combat by the amount of information which he is required to monitor, to evaluate, and to act upon.
- There is conflict between the "look-down" displays, in the fixed area of the panel, and the "look-up" display which is represented by the view through nearly the entire canopy.
- In close, air-to-air combat, the "look-up" display has priority; therefore, critical visual displays should be transferred to the helmet presentation.

- The sighting portion of the helmet system is justified on the basis of the ability to simultaneously select a target and train weapons on it, with the verification being inherent in the original selection. The helmet sight allows manipulation of two new control channels without requiring the pilot to be equipped with more than his normal allotment of hands and feet.

Returning to Table II, the columns and rows corresponding to the helmet sight and to the helmet display show the potentially useful linkages between these two items and the sensor complement.

The column (1) under helmet sight would normally be empty because the sight is directed only by the pilot, there being no servo or control linkage into it from the other equipment. Also the row (2) extending to the right from helmet display would normally be empty because it ends at the pilot and exerts no direct control of the other elements listed. A linkage between the helmet display and the helmet direction sensors can be cited as a special use of the HMS/D. As an example, the head can be manipulated to match cueing elements in a display to those of a fixed display. This utilizes the direction sensing elements of the helmet sight system and is useful for directing the pilot's head toward a target which will eventually come into view. The unique thing about this type of display is that the external view through the helmet sight may not at first have significance. This category of operation is special and accounts for the fact that applications appear in spaces (2) (1) and (3) (1) on Table II.

Column (2) on Table II lists five important inputs to the helmet-mounted display; these are of immediate importance to the air-to-air combat situation:

- Main radar display (3) (2)
- Identification device display (4) (2)
- Missile seeker display (6) (2)
- Rear warning indication (7) (2)
- Radar receiver (8) (2)

Row (1) lists four important uses of the helmet sight as a control device in air-to-air operations:

- Directing the main radar
- Directing the identification device
- Directing the missile seekers
- Directing the pilot's head by presentation of cues

A flexible gun could be a fifth item directed by the helmet sight system; however, it is not likely that a flexible gun will be part of the F-15 weapon complement.

Of the five listed uses of the helmet display, the first three are basically for attack and the last two are defensive. A brief discussion of display uses follows.

It is clear that the five cited displays cannot be presented in their entirety full time; this would seriously overload both the pilot and the display. Fortunately, simultaneous display is not necessary. A system of selection and presentation in which displays appear, or can be made to appear exactly when needed, without seriously cluttering the field or excessively loading the pilot is required. It should be mentioned that close air-to-air combat is by its nature a condition of pilot overload, and it is unrealistic to suggest that any system will completely eliminate this overload. The objective must be a system which minimizes overload by allowing pilot concentration on those items of immediate importance at any given instant.

In dealing with the five cited display items, a particularly interesting problem appears in the interplay between the three attack and the two defensive functions. Adequate concentration for search and attack must be possible simultaneously with proper monitoring of the two warning devices. Partial relief may be obtained by placing audio tones denoting radar receiver or rear warning detector responses on the communications headset. Some automatic processing of signals from these defensive devices can be accomplished to establish the degree of urgency of the threat. In the case of the rear warning device the degree of urgency grows with both the strength and the duration of the response. In the case of the radar receiver, the sector in which the threat occurs must be considered in the automatic assessment of urgency because of the dependence of closure rates. When the urgency r aches some predetermined level, a display should automatically appear on the helmet unit showing number of threats together with directional data. This must share the helmet display with one or more of the three attack inputs. The choice of a particular procedure for the interruption of existing displays should be made on the basis of experimental results and on the preference of the pilots who will work with the system. Pilots have stated that they do not want warning of even the most urgent threats during certain parts of an attack since even a moment's distraction may rob them of a kill.

SECTION VI

HMS/D BASELINE SYSTEM AND ITS INTERFACE WITH AIRCRAFT

In preceding sections, concepts of HMS/D use in high-performance fighters have been develcped. Consideration has been given to the probable complement of sensing equipment aboard the F-15, and means of integrating the HMS/D with the sensor complement have been discussed. Consideration must now be given to the combination of the desired HMS/D functions into a single system and the integration of that system to the probable F-15 aircraft.

HMS/D functions required by the applications considered in this report are summarized in Table III. The HMS/D system designed to meet all the needs outlined in Table III would probably be satisfactory to most purposes in any high-performance aircraft with only minor modification. For consideration in regard to the F-15, the reconnaissance functions probably have less meaning than in a craft more specifically designed for reconnaissance missions.

Since the primary purpose of the F-15 is to engage enemy craft in the air, those functions which are applicable to that mission tend to define a basic HMS/D system. Such a system should be capable of assisting the pilot in the performance of those functions which must be carried out during air-to-air combat engagements. In light of pilot comments relegating threat warning to a secondary position of importance, only offensive combat operations will be included in the basic system implementation. The resulting system might be considered the minimum weapon delivery system based on the HMS/D. Other functions added to it later must be so implemented that the use of the basic system is not jeopardized.

SYSTEM REQUIREMENTS

Requirements for the basic system include the following:

Scene displays:	Radar plot (including gate symbol) E-O tracker (including gate symbol)
Symbols:	Radar direction cues (2) Range-to-target indicator Sight reticle Steering symbol Radar unlock warning
Symbols driven by:	Radar direction angles Radar range Computer lead-angle calculations

Helmet sight pointing commands to:	Radar antenna azimuth and range gate Identification device tracker Radar antenna azimuth and elevation E-O missile tracker Display stabilization computation
HMS/D operating modes:	Radar search Radar acquisition Identification Medium-range missile launch Short-range missile launch Gun fire control Quick radar lock
Interface requirements:	Radar mode remote selectable Radar with fast lock mode at short range Final weapon selection via HMS/D mode control Ability to switch control channels quickly Ability to control more than one sensor at a time

A block diagram of a system to implement these requirements is shown in Figure 26.

The diversity of information sources and destinations and the complexity of the switching functions involved in meeting the basic requirements point to use of the aircraft computer as the principal interface element. Scene imagery does not lend itself to such an interface and therefore is handled separately. The computer is used to transfer information, to scale data up or down for display purposes, to establish addresses on the display for particular information or symbols, and to transmit commands relative to mode changes to the various system elements.

The variety of display elements points to the use of a cathode ray tube (CRT) as the display element. Since the E-O trackers will most likely require a raster scan display, conversion of radar scenes to that form seems the best approach. Symbol generation and positioning can also be made compatible with that form of display. Video amplification, synchronizing circuits, and controls required for the CRT must be added to the system at this point. The CRT controls will generally be set on the ground and will not enter into the flight regime with the possible exception of the brightness control. All functions called for in the system are well within the state of the art.

Table III. Summary of HMS/D System Functions

Event		Scene Display	HMS/D Generated Symbols Displayed	Equipment Controlled by Helmet Sight	Helmet Sight Information Used to Compute	HMS/D Modes	HMS/D Controls Required
Air-to-Air Combat Functions							
Radar search		Radar Plot	None	None		"Search"	Mode control
Radar lock (distant)	Before lock	Radar Plot including gate symbol	None	Antenna position in azimuth. Range gate position		"Radar Acquisition"	Mode control Acquisition switch Radar antenna elevation
	After lock	None	Cues and range	None	Cue position		None
Long-range identification		E-O tracker video including gate symbol	Radar cue Radar range (if radar is locked)	Tracker pointing (before lock)	Cue position Cue blanking	"Identify"	Mode control Acquisition switch
Medium range missile (semi-active)	Radar locked	None	Radar cue Radar range	None		"MRM"	Firing switch
	Lock broken	Automatic switch to "quick radar lock" Mode					
Quick radar lock		None	Sight reticle	Radar pointing in azimuth and elevation		"MRM" "Guns"	Acquisition switch
Short-range missile (E-O"	Before lock	E-O tracker video including gate symbol	Radar cue Radar range (if radar is locked)	Missile tracker Radar pointing (if radar not locked)	Cue position Cue blanking	"SRM"	Acquisition switch Mode control
	After lock		Radar range	None			Firing switch
Gun firing	Radar	None	Radar unlock warning Steering symbol	None	Stabilization of display in front of windshield	"Guns"	Firing switch Mode control
	Radar unlocked	Pilot may switch to "quick radar lock" manually					Acquisition switch
Other HMS/D Functions							
Air-to-ground target location and identification		E-O tracker video	Target location cues (3)	E-O tracker (before lock)		"Ground target"	Mode control Acquisition switch
Air-to-ground missiles - E-O and semi-active		Same as air-to-air except for ground target cues					
Air-to-ground gunfire		Same as air-to-air					
Threat warning		None	Warning symbols or message	None		All	None
Navigation update		None	None	None	Aircraft position	"Navigation update"	Mode control Acquisition switch Update command
Terrain following		Terrain radar	None	None	Display stabilization	"Terrain"	Mode control
Landing		Landing display	Status and warning messages	None	Display	"Landing"	Mode control
Reconnaissance		Ident. telescope or other sensor (when commanded)	None	Sensor pointing (when commanded)	Target	"Recon"	Mode control Acquisition switch Ident. keyboard Sensor selector

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T ble III. Summary of HMS/D System Functions

HMS/D Generated Symbols Displayed	Equipment Controlled by Helmet Sight	Helmet Sight Information Used to Compute	HMS/D Modes	HMS/D Controls Required	Other Conditions Established
Air-to-Air Combat Functions					
None	None		"Search"	Mode control	Radar plot on helmet display via scan conversion
None	Antenna position in azimuth. Range gate position		"Radar Acquisition"	Mode control Acquisition switch Radar antenna elevation	Radar plot on helmet display via scan conversion. Radar mode changed by mode control setting.
Cues and range	None	Cue position		None	
Radar cue Radar range (if radar is locked)	Tracker pointing (before lock)	Cue position Cue blanking	"Identify"	Mode control Acquisition switch	Radar may be pointed and locked at same time if previous lock is broken.
Radar cue Radar range	None		"MRM"	Firing switch	Weapon selection
Automatic switch to "quick radar lock" Mode					Radar switched to automatic range gate operation.
Sight reticle	Radar pointing in azimuth and elevation		"MRM" "Guns"	Acquisition switch	Radar switched to automatic range gate operation
Radar cue Radar range (if radar is locked)	Missile tracker Radar pointing (if radar not locked)	Cue position Cue blanking	"SRM"	Acquisition switch Mode control	Weapon selection If radar is not locked acquisition switch locks missile tracker and radar at same time.
R. dar range	None			Firing switch	
Radar unlock warning Steering symbol	None	Stabilization of display in front of windshield.	"Guns"	Firing switch Mode control	Computer drive of steering symbol to provide lead compensation
Pilot may switch to "quick radar lock" manually				Acquisition switch	
Other HMS/D Functions					
Target location cues (3)	E-O tracker (before lock)		"Ground target	Mode control Acquisition switch	Radar slaved to HMS/D and locked with E-O tracker. Tracker triangulation program enabled.
Same as air-to-air except for ground target cues					
Same as air-to-air					
Warning symbols or message	None		All	None	
None	None	Aircraft position	"Navigation update"	Mode control Acquisition switch Update command	Triangulation on target required
None	None	Display stabilization	"Terrain"	Mode control	
Status and warning messages	None	Display	"Landing"	Mode control	
None	Sensor pointing (when commanded)	Target	"Recon"	Mode control Acquisition switch. Ident. keyboard Sensor selector	

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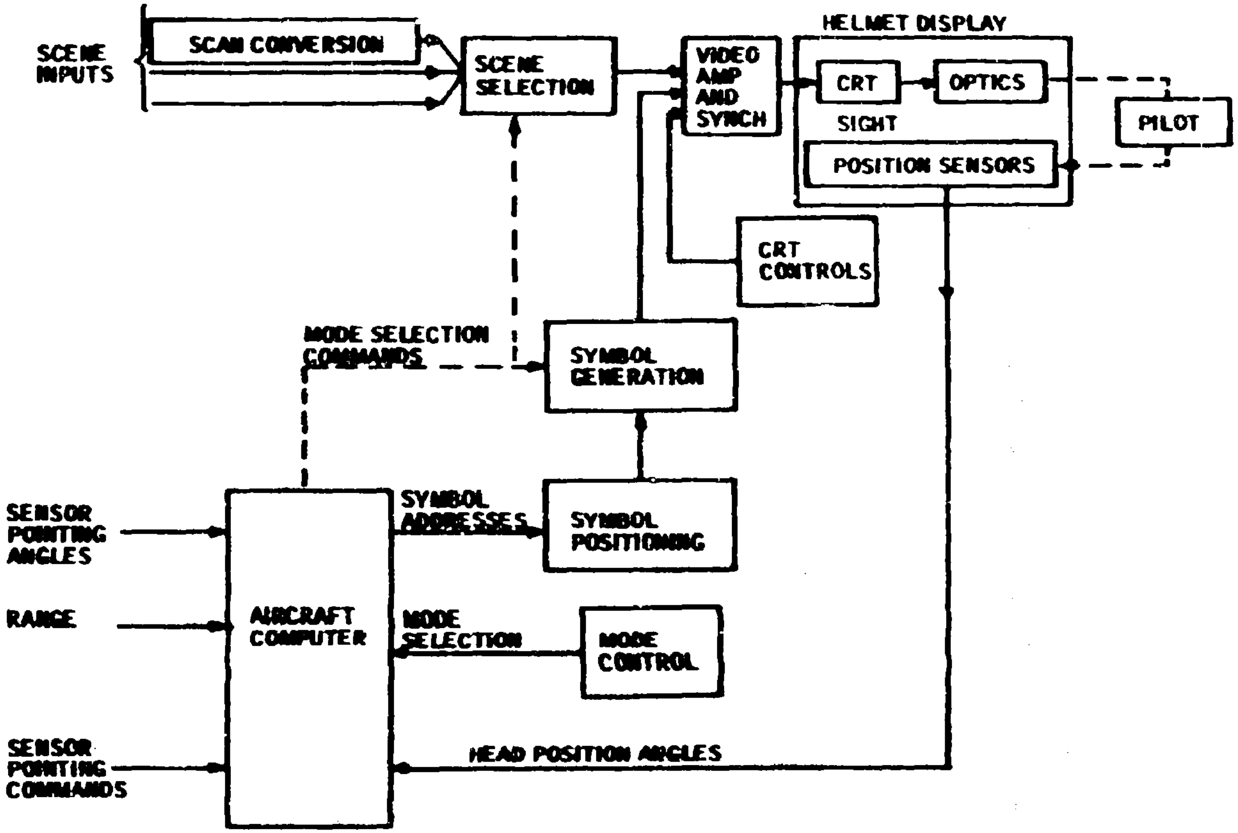

Figure 26. Basic HMS/D System Block Diagram

CONTROL REQUIREMENTS

The basic HMS/D system requires the following controls:

- HMS/D mode control
- Acquisition switch
- Firing switch
- Radar antenna elevation control

The final three of these four controls already exist in fighter craft, and they therefore do not represent any addition to the cockpit. The fact that only elevation of the radar antenna is controlled manually represents a simplification of cockpit controls, since the stick controller for antenna azimuth and range may be omitted when the antenna is controlled by the helmet sight. The manner in which the controls are used is described in the following paragraphs.

- Radar Search - The standard azimuth-versus-range plot is displayed on the helmet instead of on a cockpit-mounted scope. Search is conducted in the normal manner using manual adjustment of the antenna elevation. Selection of the "Search" mode automatically connects the radar imagery through the appropriate scan converter.

- Radar Lock (distant) -Placing the mode control in the "Radar Acquisition" position changes the radar to its acquisition mode and connects the helmet sight to the antenna and range gate positioning circuits. Helmet azimuth position controls antenna azimuth and helmet elevation controls range rate position. Radar lock is completed using these controls and the acquisition switch. Manual adjustment of antenna elevation is used as required. Upon radar lock, the radar display is removed and an HMS/D generated display of directional cues and range to target is substituted. Inputs to this display and the command to change over are supplied from the radar through the aircraft computer.

- Long-Range Identification (E-O tracker) - Selection of the "Identify" position on the mode selector places the video output of the electro-optical identification device on the helmet display along with the range data and radar position cues. If the radar is not locked, only the video appears. It is expected that the tracker video will include a gate or other aiming symbol. The helmet sight points the identification device, with the helmet azimuth and elevation notions controlling the respective motions of the tracker with one-to-one scaling. The pilot brings the identification device around that line. If the target is directly

visible, the target itself is sighted. When the target appears in the identification device field of view the tracker may be locked to the target or identification may be made without locking the tracker. As an option, it is possible to aim the radar along with the identification device and lock the radar and identification tracker at the same time. This option would be valuable as insurance against broken radar contact during the alignment of the identification device.

- Medium-Range Missile Attack (semi-active guidance) -- In the "MRM" mode, when the radar is locked, the mode control activates the missile which has been pre-selected by the pilot. Radar range and direction cues are displayed on the helmet display. When the range requirements are met, the missile is fired by means of the firing switch. If radar lock is broken in this mode, the aircraft computer commands an automatic mode change to allow quick relocking of the radar. An interlock prevents firing till lock is re-established.

- Quick Radar Lock -- This mode is selected either automatically from the "MRM" mode or manually in the "Guns" mode. It provides a rapid means of directing the radar to a target at close range. The helmet motions in azimuth and elevation drive the corresponding axes on the radar bringing the radar direction to the pilot's line of sight. The acquisition switch causes an automatic range gate to move outward and lock to the nearest target. Relock of the radar automatically returns the system to whichever mode was originally selected. Note that the quick radar lock mode is not commanded by the mode control directly, instead, the mode is set up by mode control selection of "MRM" or "Guns" and the simultaneous occurrence of a radar unlock. In the "Guns" mode, the transfer is optional and must be commanded.

- Short-Range Missile Attack (electro-optical guidance) -- In the "SRM" position, the mode control again has a weapon activation function, setting up the pre-selected short-range missile for firing. It also places the output of the missile E-O tracker and the radar range indicator on the helmet display and connects the helmet sight to the tracker such that azimuth drives azimuth and the elevation drives elevation with a one-to-one scale. The pilot views the target through the tracker, places the tracker gate on the target and locks the tracker by pressing the acquisition switch. When range requirements are met, he fires the missile by closing the firing switch. A desirable option in this mode is to slave the radar to the helmet at any time the mode is selected with the radar unlocked. Lock of the radar in the manner described for the quick radar lock mode and of the missile tracker would occur simultaneously when the acquisition switch is operated.

- Gun Fire Control -- When the mode control selects "Guns", the reaction depends on whether the radar is locked. If not, the quick radar lock mode is automatically selected. When the radar is locked either at the time the "Guns" mode is selected or later by means of the quick lock technique, the steering symbol of the director gun sight is displayed. The outputs of the helmet sight are used to position the entire display such that it remains aligned over the fore-aft axis of the aircraft regardless of head position. The aircraft computer calculates the required lead compensation and positions the steering symbol accordingly. If the radar unlocks after originally being locked, the pilot may either continue the attack with a fixed range inserted in the calculation automatically or he may go to the quick radar lock mode by pressing the acquisition switch. The option is left with the pilot rather than providing an automatic transfer since the circumstances of the particular attack will determine whether an effort should be made to re-lock the radar.

  The operation of the four controls used with the HMS/D in air-to-air operation is summarized schematically in Figure 27. Each event in the idealized combat sequence can be controlled using the four controls specified. The transitions from event to event can be made with a minimum of looking into the cockpit. In addition, the sequence may be entered at any point by setting the mode control and without requiring any special procedure to carry out the desired functions. Manual control is preserved in all cases where an option exists with the idea that the best judgment available aboard the aircraft is that of the pilot.

DISPLAY REQUIREMENTS

Table IV lists the display elements required for the basic HMS/D system. The size, appearance, motions and uses of each are summarized. Three are "scene"-type displays and eight are symbols or graphics.

Of the three scene-type displays, two are TV views generated by electro-optical seekers and one is a radar map generated by the radar set operating in its scan mode. Any of the three scene displays selected will be fixed on the helmet CRT, therefore the displays will remain fixed in the pilots view regardless of look direction.

Of the eight symbol-type displays, five are fixed to the helmet CRT and are carried with the head as are the three scene displays. The three symbols which must be moved about on the display require appropriate electronics for x and y translation. This is not simply a matter of providing x and y positioning voltages such as are used on oscilloscopes since it is necessary that the scan raster be fixed and the symbol be moved within the raster.

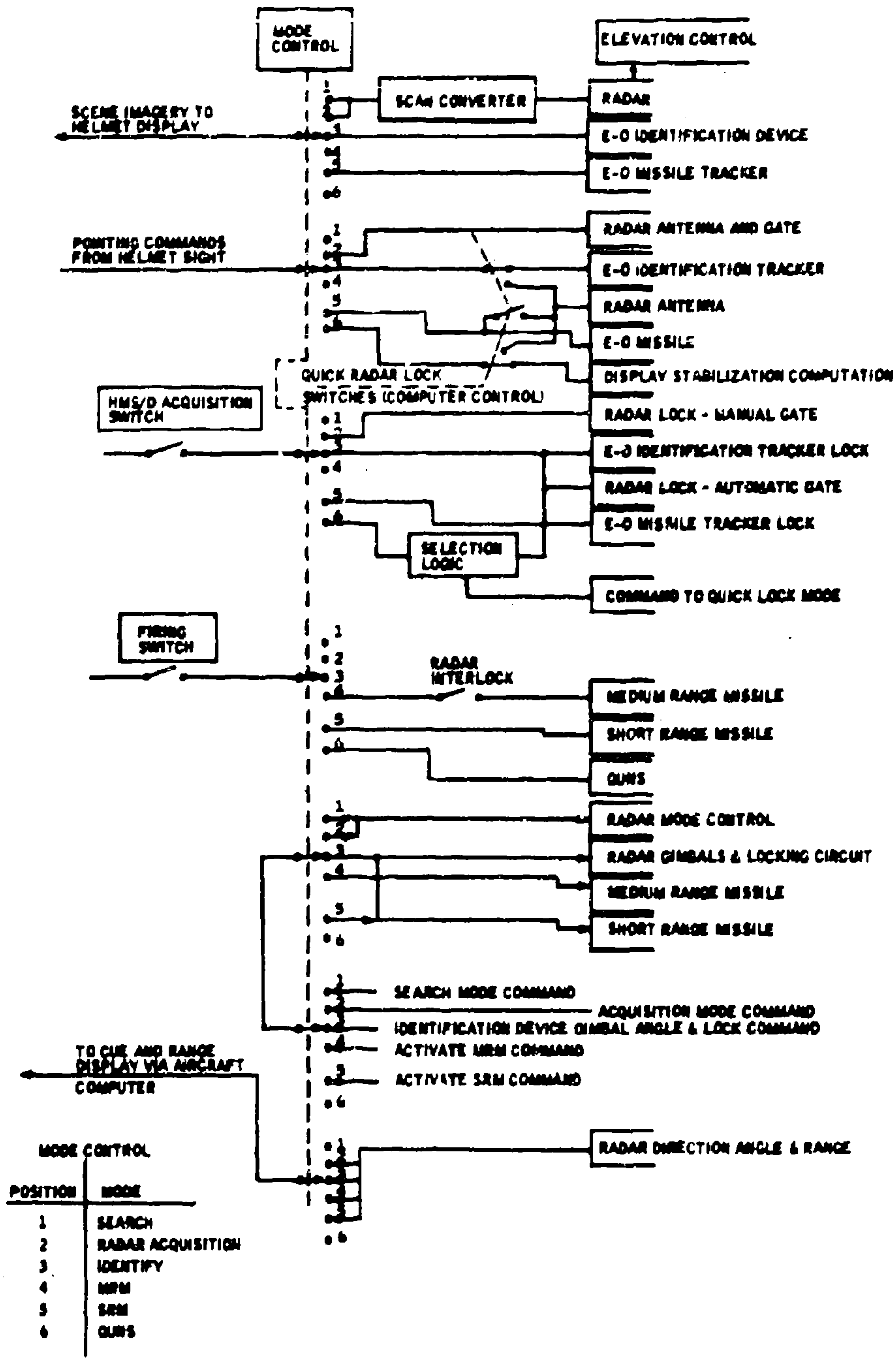

Figure 27. Schematic Relationship Among HMS/D Controls

Table IV. Basic System Display Requirements

Display	Type	Approximate Size	Coord. System For Display	Display Uses	How Generated	How Translated (on Helmet CRT)	Comments
Sighting direction	Symbol	Small, approx. 1.0 degrees (17 TV lines)	Fixed to head; occupies center of helmet CRT; independent of head direction.	Sighting reference (radar quick lock)	Symbol generator	Not translated; fixed on helmet CRT	As alternative, this sighting symbol can have optical origin rather than being generated by symbol generator
Radar map	Scene	10° to 15° square	Fixed to head; occupies nearly full helmet CRT; independent of head direction	Map monitored for target appearance	Video and sync. pulses supplied by radar set or scan converter	Not translated; fixed on helmet CRT	Map automatically vanishes when radar dish moved toward lock
Radar gate symbol (on radar map)	Symbol	Small, approx. 1.5 degrees (26 TV lines)	Moves on helmet CRT as head is moved	Represents head angles (scaled to display size) use for directing radar dish	By radar	Translated on radar by head angle data provided by helmet system	
Radar cue	Symbol	Small, approx. 1.5 degrees (26 TV lines)	Moves on helmet CRT; fixed to direction of locked radar dish. Replaced with arrow cue if radar cue off display field.	Represents direction of locked radar beam. 1:1 scale with real world use for directing eye or EO seeker to target	Symbol generator	Translated on helmet CRT by angle data which is difference between head angles and radar dish angles.	
Radar range	Bar scale moving pointer	Small, 1.5° high (26 TV lines)	Fixed to head, stays at lower edge of helmet CRT	Tactical uses for range, range rate and lethal range envelope	Symbol generator	Not translated; fixed on helmet CRT Pointer moved by computer control	Loss of display indicates radar unlock
Identification device imagery	Scene	10°-15° square	Fixed to head; occupies nearly full helmet CRT	Provide magnified image of target for early identification	Video and sync. pulses supplied by sensor TV electronics	Not translated; fixed on helmet CRT	
Identification device gate	Symbol	Not known	Fixed to head; occupies center of helmet CRT	EO tracker locks when tracking gate placed on target	Symbol video supplied by I.D. device electronics	Not translated; fixed on helmet CRT	
E-O seeker view	Scene	10°-15° square	Fixed to head; occupies nearly full helmet CRT	Confirm target selection by identifying in field of missile E-O tracker	Video and sync. pulses supplied by missile seekers TV electronics	Not translated; fixed on helmet CRT	
E-O seeker gate	Symbol	Not known	Fixed to head; occupies center of helmet CRT	Missile E-O tracker locks when tracking gate placed on target	Symbol video supplied by seeker TV electronics	Not translated; fixed on helmet CRT as part of missile E-O generated signal	
Gunsight steering symbol	Symbol	Small approx. 1.5 degrees (26 TV lines) Moves ±10° in Az. and Elev.	Moves on helmet CRT; represents lead angle for target	Aiming and firing reference for gunnery	Symbol generator	Translated on helmet CRT by head angle data plus ballistic and lead computation	Must be stabilized relative to aircraft armament datum line
Radar unlock warning	Alpha-numeric	Small, approx. 1.5 degrees (26 TV lines)	Fixed to head	Warns of radar unlock during gunfire	Symbol generator	Not translated	

Most HMS/D applications require that symbology as well as scene imagery be provided. Often there is call to mix the two and to move symbols over the the scene. Status and warning signals may require alphanumeric messages on the display, further complicating the display requirements.

The only practical and presently available display device capable of presenting the complex formats required is the cathode ray tube (CRT). Such tubes are available in sizes and resolutions suited to the requirements of helmet mounting, and the known characteristics of the tubes make them potentially useful in airborne applications. While high voltages are required, the safety problems caused by such voltages are not difficult to overcome. A method of using the CRT to meet HMS/D needs is shown in Figure 28. The CRT section includes the video amplifier, both sweep generators and the control elements. For the three scene displays, the video amplifier and the sweep generators are driven by the "scene" electronics selected. When no scene is displayed, the sweep circuits are self-triggered to generate the raster needed for symbol display.

Of the five symbols generated by the HMS/D system, two must be translated in both x and y directions on the CRT raster. This is done in the symbol position control section shown in Figure 28. The horizontal position of the beam is represented digitally by an oscillator-driven counter, which is reset at the end of each horizontal sweep. The oscillator frequency is such that there are as many resolution elements horizontally as there are scan lines vertically. Vertical position of the beam is represented by the actual scan-line count, the counter being driven by the horizontal sweep trigger and reset by the vertical sweep. The counts are fed to a pair of address registers, along with digital x and y angle data, to generate x and y positioning controls. These are fed to the symbol logic section and control the raster position of the selected symbol to one-line-width accuracy. For the two nontranslating symbols which are generated by the system, fixed values are applied to the angle control inputs to the address registers. These hold the symbols in the center of the raster. If more than one symbol is to be positioned at a time, additional address registers are required. For symbols which appear at fixed positions on the display, fixed commands replace the outputs of the angle-to-position conversion.

EXPANSION OF THE BASIC SYSTEM

The basic system described will perform the offensive requirements of the air-to-air combat mission satisfactorily. For consideration of a baseline HMS/D which has capabilities beyond the very minimum, consideration should be given to the addition of other functions. Examination of Table III shows that very little must be added to the basic system in order to implement air-to-ground as well as air-to-air combat functions.

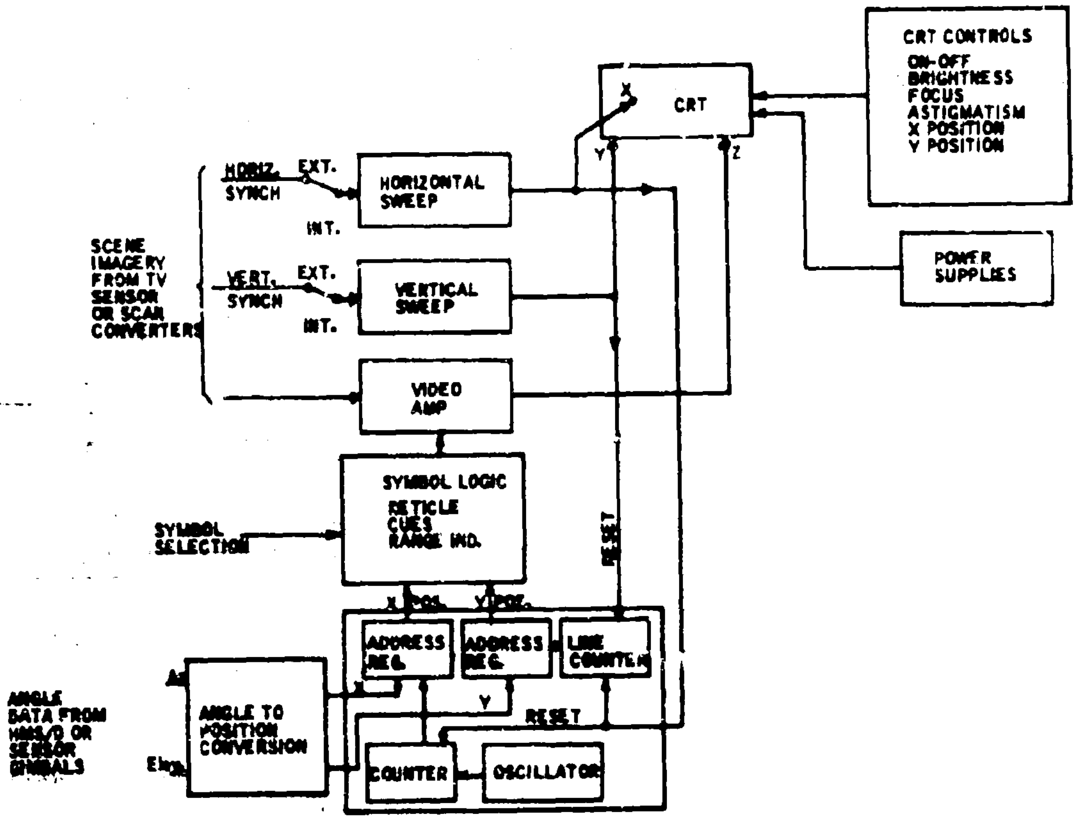

Figure 28. Use of CRT to Provide Flexible Display Format

Target identification in air-to-ground is similar to that specified in the original system but calls for the addition of the triangulation location of the target on the ground. Similar triangulation calculations are called for in the navigation update operation.

Terrain following, landing, and reconnaissance uses call for major additions to the basic system. Terrain following and landing each require the display of entire new formats of information. Reconnaissance calls for the addition of a target identification keyboard, a data encoder, a data transmitter, and controls for whatever complement of sensing devices is included.

Threat warnings and aircraft status and warning information may call for a wide variety of symbols and characters. In a fighter aircraft, however, simplicity is a prime virtue. To provide the most readable display, an arbitrary limit to the number of symbols presented should be applied for the beginning of development. Additional information can then be added as needed. From examination of the information evolved on HMS/D uses, a list of system tasks was chosen. These tasks form the basis for definition of a baseline HMS/D system. They include the prime air-to-air combat functions of the F-15 completely. Addition of the weapon delivery tasks in air-to-ground combat calls for relatively little system complication.

Beyond the weapon delivery and other combat applications, the baseline system should include others which are representative of the flight control and navigation functions required by the aircraft. These functions should be held to the minimum necessary to show the capability of the system in order to prevent overcompilation of the first implementation of the HMS/D. On this basis, the following tasks were chosen for implementation in the baseline system:

- Air-to-air combat
  - Radar search and lock
  - Identification
  - Missile control
  - Gun control
- Air-to-ground combat
  - Visual search and tracker lock
  - Identification
  - Missile control
  - Gun control
- Navigation
  - Navigation update
- Flight control
  - Landing assistance

BASELINE SYSTEM CONFIGURATION

A system suited to performing the baseline tasks is outlined in Figure 29. The major interface between the HMS/D system and the aircraft is the aircraft computer. The computer fills the following functions in the system:

- Conversion of sensor gimbal angles to symbol addresses
- Conversion of head-position angles to sensor pointing commands
- Routing of information and commands in accord with mode selection
- Calculation and comparison of target and checkpoint coordinates

To utilize the HMS/D system, information must flow between it and the following aircraft subsystems:

- Main radar
- Identification device
- Electro-optical missile trackers
- Inertial navigator
- Landing display generator.

The helmet-mounted display is mechanized as a raster scanned cathode ray tube display with projection optics to place the collimated image of the tube before the pilot's eye. The raster characteristics are tailored to the standard adopted for television sensors aboard the aircraft. It is assumed that this standard will apply to the long-range identification device and to any electro-optical missile trackers used in the weapon system. To present radar information, scan conversion is required. Scan conversion may also be required for the landing assistance display, depending on the manner in which it is generated. In the system diagram, the landing display is shown as an externally generated input. The display could be generated within the HMS/D system and, for a fully integrated, final system, probably should be. For a developmental baseline, however, the additional complexity of symbol generation required for a landing display will tend to remove attention from the basic HMS/D requirements. Integration of landing display generation to the HMS/D system was therefore deferred to later in the development cycle.

The HMS/D mode selection is interlocked with the weapon selection controls in such a manner as to allow the weapon panel to be set up prior to an engagement. The final choice of weapon to be fired is then tied to the selection of the aiming mode for that particular weapon. Thus, the pilot may use his armament controls to arm both a short-range missile and his guns before starting an attack and make the final selection as to which will be fired by his selection of either the "Guns" or "SRM" mode for the HMS/D. By proper choice of control design and location this approach maximize the time the pilot may devote to viewing the world outside his cockpit during the actual engagement.

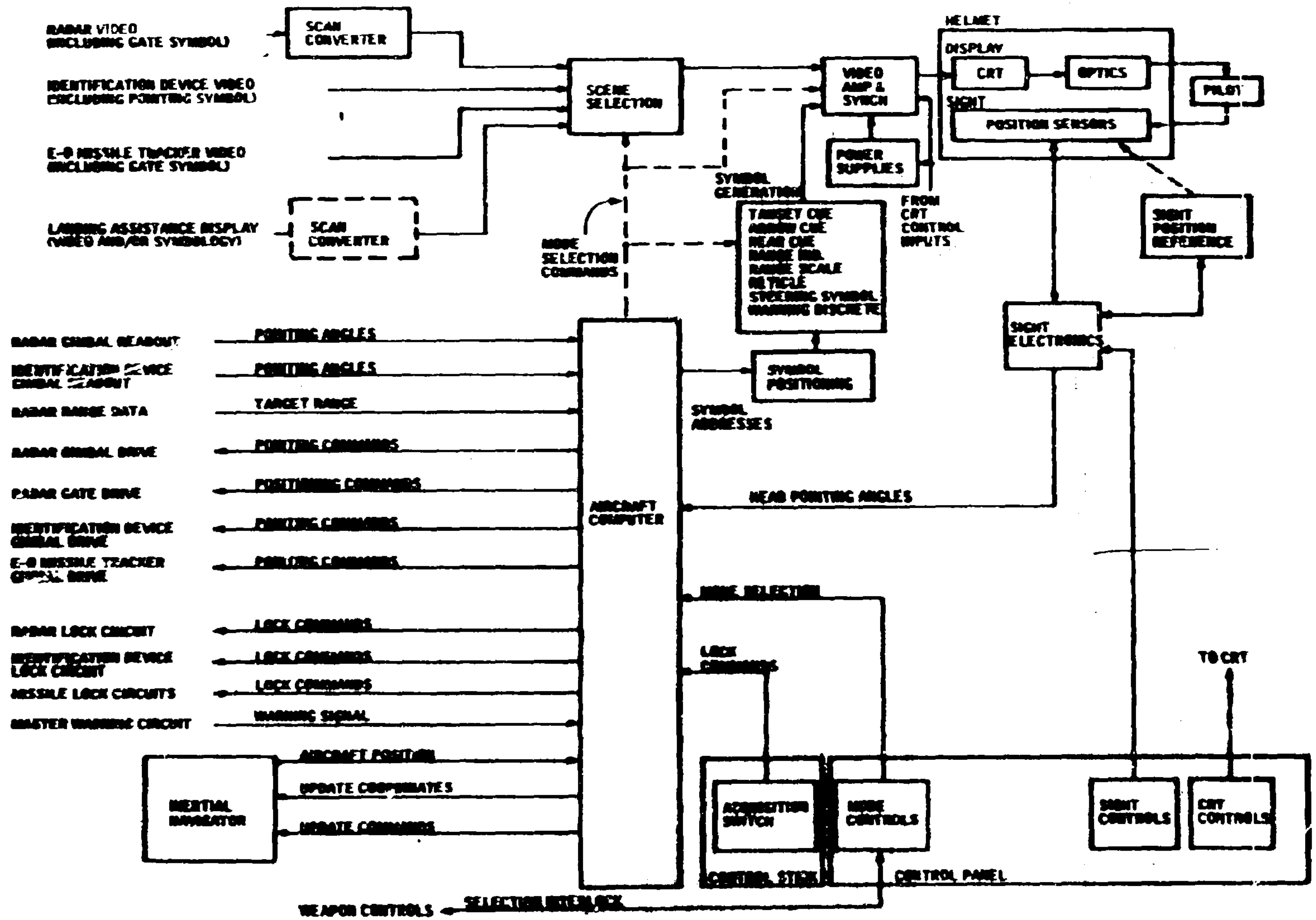

Figure 29. Baseline System

The symbol positioning system utilizes address commands generated in the computer to locate selected symbols on the display. Symbols having a fixed location on the display do not require constant re-addressing after the original command. The total number of symbols to be generated may be kept small by utilizing the same symbols for several purposes. The baseline system requires the following symbols:

- Target cue 1 - used when the target is within the display field.
- Target cue 2 - used when target is outside the display field but within reach of the pilot's head motion.
- Target cue 3 - used when the target is out of the pilot's range of head motion.
- Range indicator - moved to a point which shows the target range.
- Range scale - the scale against which the range indicator is read.
- Reticle - used as a sight for the quick pointing of the radar.
- Steering symbol - used to direct the pointing of the aircraft during gun firing.
- Warning discrete - used to indicate the occurrence of a critical condition.

The uses of these symbols have been described previously with the exception of the warning discrete. Warnings of critical or non-critical failures within the aircraft are a valid use of the HMS/D. However, there is a question as to which conditions should be covered by the warning system. At this stage of development, the provision of a master warning signal tied to the aircraft's fault location subsystem will allow implementation of a typical warning circuit and provide the developmental work required to make other, more complex warning indications available later. A single alphanumeric message of fixed content and location will provide the warning function without adding unduly to the overall development complexity of the system.

AIRCRAFT INTERFACES

The baseline HMS/D system, as illustrated in Figure 29, has two major interfaces. Video imagery interfaces with all sources (radar, E-O trackers, etc.) are at the scene selection circuit inputs. All other interfaces are at the aircraft's central digital computer. This choice of interface is shown since the tendency at this time is toward digital interfaces. It is equally possible for the system to be mechanized with either digital or analog interfaces either through a central point or with the various individual aircraft subsystems.

Present-day helmet sight outputs are particularly suited to digital computer interfaces. However, helmet sight mechanizations have been successfully built with analog interfaces using linear d-c, linear a-c, or synchro outputs from the helmet sight. The sight system is extremely flexible in its electronic interface with the aircraft. Integration of the sight system to the

aircraft cockpit will require the installation of equipment for linking the helmet to the remainder of the system. Two principal approaches to this have been explored. One senses helmet position by a mechanical linkage between the helmet and the aircraft structure. The other provides the position-measuring link by way of beams of light and requires no physical connection between helmet and aircraft. The latter approach is preferable, particularly in a single-place fighter where the utmost in pilot head-positioning flexibility must be provided. If this method of measuring head position is used, the only new requirement for interfaces in the cockpit is the mounting of the light beam source(s) at the proper points in the cockpit. The optimum location for light beam sources is at the level of the sensors on the helmet and to the rear of the helmet center line. Actual location must be fitted to the design of the particular aircraft.

The integration of the helmet display to the aircraft can be performed as illustrated in Figure 29, where the major interface point for all aircraft subsystems is in the aircraft's computer, or it may be made with each of the interfacing components directly. Selection of video inputs to the display may be made by discrete command from switches as well as under computer control and transfer between scene inputs may be made automatic by inclusion of the appropriate logic circuitry in the scene selector. Symbol position commands may be provided in either digital or analog form with the appropriate changes in the positioning circuitry.

The extreme flexibility of the HMS/D system in interfacing with other components makes it possible to consider retrofitting it to existing aircraft as well as fitting it to new aircraft during the initial design of the craft. The small dimensions and crowded conditions of some existing craft other problems for location of the helmet sight light beam generator(s); however, locations have been found for use in flight tests with F-4 and RF-4 aircraft and can similarly be found for others. Continuing development work with the light beam sources has reduced the space required for them significantly, and additional reductions are expected in the near future. Thus, the mechanical integration problems with existing aircraft are being reduced with time.

SECTION VII

INTEGRATION OF HELMET-MOUNTED EQUIPMENT

In providing the HMS/D functions, equipment must necessarily be mounted on the pilot's helmet. Any additions, though, may cause unwanted side-effects which interfere with the pilot's normal functioning. A workable arrangement must avoid unnecessary additional weight on the helmet, prevent unbalances which would develop high torques on the pilot's head during acceleration, provide unobstructed vision to be the highest degree possible, and maintain the required relation between components in order to maintain alignment accuracy. An approach which simply hangs equipment on the outside of an existing helmet seems unlikely to achieve satisfactory results in all of these areas. A better approach is to consider the entire helmet as a subsystem and provide the necessary integration to bring the best results.

Figure 30 shows one approach to the design of an integrated helmet. The cathode ray tube is built into the side of the helmet, providing the lowest location and the position closest to the center line of the pilot's head. The sensors for the helmet sight head-position measurement system are molded into the housing for the sun-visor. The projection optics for the display fasten to the front of the cathode ray tube and project an image across an open space to the image combiner mounted before the pilot's eye. The combiner is retractable upward behind the sun visor. The projection optics may be stowed by rotating them out of the way.

BASIC HELMET CONSIDERATIONS

Until a few years ago, the scientific community appeared to take little real interest in helmet characteristics other than impact attenuation - i. e., factors such as a desirable helmet cg location, maximum allowable mass, the effects of additional devices on the helmet, and various suspension systems Possibly it is not lack of interest but rather lack of technique; it is virtually impossible to determine the causes of neck injury without systematically injuring a lot of necks!

A number of problem areas have become evident simply through the daily use of helmets. These range from discomfort, which is perhaps of little importance in itself but may lead to fatigue which can be a dangerous factor in a combat situation, to severe blockage of vision which may be fatal in combat.

The major complaints registered against existing helmets fall into the following general categories.

Figure 30. Integrated Helmet Concept

- They are uncomfortable.
- They are too hot.
- They move around on the head, particularly under high-acceleration maneuvers.
- They restrict vision by protruding into the peripheral vision areas.
- They restrict vision by preventing the pilot from getting his eyes close to the canopy.

Any helmet-mounted equipment must take these complaints into consideration. Components must be so arranged that they at least do not aggravate the present situation. More desirable would be for the design of an integrated helmet/sight/display combination to alleviate the present helmet problems.

While complete research of helmet design is far beyond the scope of the present study, information has been compiled which will direct effort toward a workable integrated helmet. Discussions have been held with a number of medical researchers in the field, with pilots, and with helmet manufacturers. The following paragraphs summarize the information gained.

- Helmet design has historically been handled as an art -- safety has not been considered in a scientific manner.

- Crash helmet design is only now becoming scientific due to injuries (heavy, unbalanced, unstable helmets) and vision obscuration (slippage due to unstable helmet plus g-forces) associated with present helmets.

- It would be better to produce a heavier, balanced helmet than a lighter, unbalanced helmet . . . within rational (still unknown) limits, i.e., balance is more important than weight.

- The helmet/head combination for a given man should not (ideally) have a different center of gravity (cg) than the man's head alone. If the cg must change, then it would be more desirable to change it in the aft direction instead of forward. Lateral balance is of the greatest importance. Shifting of the cg in a vertical direction is of less importance than either laterally or longitudinally.

- Physiological effects on man due to helmet weight and balance can be grouped under three headings:

  (1) Fatigue - What is the magnitude and rate of onset of neck muscle fatigue as a function of helmet weight and balance?

(2) Tracking - How is the tracking performance of the head/ neck mechanism affected by helmet weight and balance?

(3) Safety - How is man safety under dynamic conditions (e.g., crash, g-forces, turbulence) affected by helmet weight and balance?

Of the three effects, study has primarily been applied to safety. Information on fatigue and tracking is only now becoming available.

- Sled testing has pointed to the web suspension helmet as being more stable on the head than the more traditional padded helmet. Examples of the suspension helmet are the SPH-3, SPH-4, and DH-411. There is a difference of opinion on the meaning of the tests conducted, and comments have been received that the standard padded helmet can be just as stable as the web suspension helmet provided it is properly fitted.

- The plastic housing used to protect the sun visor on a helmet is not needed if proper care is given to the helmet. The housing is a problem to the pilot because it keeps his head farther from the canopy than would otherwise be possible. It would be better to dispense with it.

HELMET ARRANGEMENT

When the conceptual helmet shown in Figure 30 is evaluated against the information outlined above, several good and bad points become apparent. The helmet arrangement shown offers great freedom from obstruction to the pilot's overall vision. The open projection path and the position of the projection optics close to the pilot's cheek leaves the field of view to the side and downward essentially unobstructed. The vision upward is obstructed only by the edge of the image combiner and its narrow support structure. For normal two-eyed vision, the sight of the unobstructed eye will fill in the gap created by the supporting structure. Use of a transparent material for the support may further reduce the loss of upward peripheral vision. The image combiner is a transparent base with a reflecting coating. The coating is chosen to provide the maximum reflectance of the light from the phosphor of the cathode ray tube and maximum transmission of all other light. This provides maximum intensity of the display and minimum attenuation of the vision from straight ahead of the pilot. The visual effect will be a slight discoloration of the scene viewed through the combiner. The edge of the combiner will provide a minor obstruction to the vision similar to the metal frame on a pair of sunglasses.

When the potential helmet arrangement is examined for possible improvement, a number of points are obvious. For example, while the CRT is at an advantageous location from the standpoint of interference with the pilot's head motion, it is far enough off the center line of his head that unless it is balanced by a similar mass on the opposite side, unwanted torques on the helmet will be developed during high-g maneuvers. Another problem area is seen in the use of two separate parts for the projection optics. Unless the helmet structure can be made rigid enough to assure the proper alignment of the projection lens with the image combiner, errors in the system will develop and the display image may be lost. In searching for alternatives, tradeoffs of the advantages and disadvantages of each possibility will be required. In the case of the optics, a physical connection between the projection lens and the image combiner may be an improvement, since the required vision downward is less vital to the fighter pilot than that directly upward.

The lateral balance of the helmet must clearly be improved, either by relocation of equipment or by counterbalancing. The latter is undesirable but less so than an unbalanced helmet. Consideration of a location for the CRT along the back of the helmet offers an improvement in the balance of the system, but creates very severe optical problems in the transmission of the image output of the tube to the eye. In spite of the optical problems, the rear location is probably the most desirable and should be the first examined for use in a practical helmet-mounted sight/display.

IMAGE-COMBINING OPTICS

Two basic approaches have been taken to helmet displays in the past. One utilizes a semi-transparent image combiner which allows the wearer to see the display presentation and at the same time see the real world beyond. There is indication that he gives attention to only one or the other, but the transition from one to the other is very easy. The other basic approach to the helmet display is to provide a periscope between the cathode ray tube and the eye. This blocks the vision of one eye to the outside-world information on the other. The periscope (or occluded) display offers a significant advantage in that it allows relatively low-level light outputs from the CRT to be visible. The wearer's eye is adapted to the display rather than to the higher light level from the sky. Questions on the long-term endurance of wearers whose eyes are differentially dark adapted have been raised but not very well answered at present. Quite aside from physiological problems with differential dark adaptation, the periscope presentation must be ruled out for use in the F-15 on the simple basis of safety. The F-15 is a single-place aircraft. If the pilot wears a device which effectively removes access of one eye to the outside world, he will be at a severe disadvantage in maneuvering his plane. The pilot must have complete vision both directly ahead and also peripherally. The occluded presentation is therefore unacceptable for the F-15.

The "see through" configuration of the image combiner causes a problem which must be considered in the configuration of the HMS/D. By allowing the pilot's vision to adapt to the relatively bright light from the sky, it requires a high intensity from the display CRT to ensure its being visible at all times. Small-format CRT's typically do not have great light output. The helmet in Figure 30 provides for display visibility in the presence of high-intensity outside light by placing the image combiner inside the tinted sun visor. Thus, the light from outside is attenuated while the display light is not. By proper choice of visor transmissibility and CRT intensity, the display may be made visible over the range of outside light intensities from darkness to 10, 000 foot-lamberts. In addition to the use of the sun visor for shading, an automatic level control for CRT intensity of the display compensates for variation in light level. The desired intensity is set manually and will then maintain the needed level of contrast by adjusting the CRT brightness in response to changes in ambient light level.

SECTION VIII
PRODUCIBILITY

DESIGN FEASIBILITY

Design of a working model of the baseline HMS/D is well within the state of the art. No radically new concepts are required. The components of a workable helmet-mounted sight have been in existence for some time and have been proven in a number of flight tests. A number of different helmet-mounted displays have been built and tested, and, while none have been completely satisfactory for flight use, they have shown that the design problems associated with their eventual perfection are not beyond solution. The major design problems foreseen are:

- Achievement of a properly balanced helmet
- Achievement of sufficient intensity from the CRT display
- Achievement of the desired field of view with sufficiently simple optical equipment

The design of the necessary electronics for the display, while demanding from the standpoint of functions to be implemented, will offer few new problems. The video circuitry problems have been met and solved many times previously. As part of the continuation of this study, a set of test bed electronics was built and is being tested. Performance has been satisfactory, and areas requiring improvement seem well within the present state of the art.

MANUFACTURING PRACTICALITY

The manufacture of the HMS/D system should be a relatively straightforward matter. The components of a satisfactory helmet sight system have been built and may be incorporated directly into the HMS/D system. The manufacture of the helmet-mounted display, while it calls for processing of optical components, will not involve precision or accuracy requirements beyond the capacity of most optical fabrication facilities. A number of helmet display prototypes have been built.

As a part of this study two test bed sight/display units were built. One of the test bed units was built without regard to either weight or balance of the helmet to provide a wide-angle, see-through display for use in simulation of the HMS/D tracking and sighting task. Emphasis was given to field of view and flexibility of adjustment. An optical design was achieved which met all needs. While heavy and clumsy, the simulator helmet performed satisfactorily and provided good results in the tracking study as well as guidance toward the solution of several design problems.

The other test bed helmet was directed more toward the problems of weight, balance, and proper integration of the HMS/D equipment and helmet. Lenses and reflectors which were immediately available from stock were used rather than custom made components. The resulting helmet is shown in Figure 31. This helmet weighs 3 lb, 1 oz, including the sun visor and all hardware. The weight can be further reduced by different choices of materials and more effective integration of the CRT. The helmet provides both the CRT display and a separate, electrically illuminated reticle. The helmet is slightly unbalanced to the right side, but gives indications of being capable of being balanced. The display field of view is 16.5 degrees because of the use of stock optical components. A larger field of view is clearly possible and is being built into the second model of the test bed HMS/D.

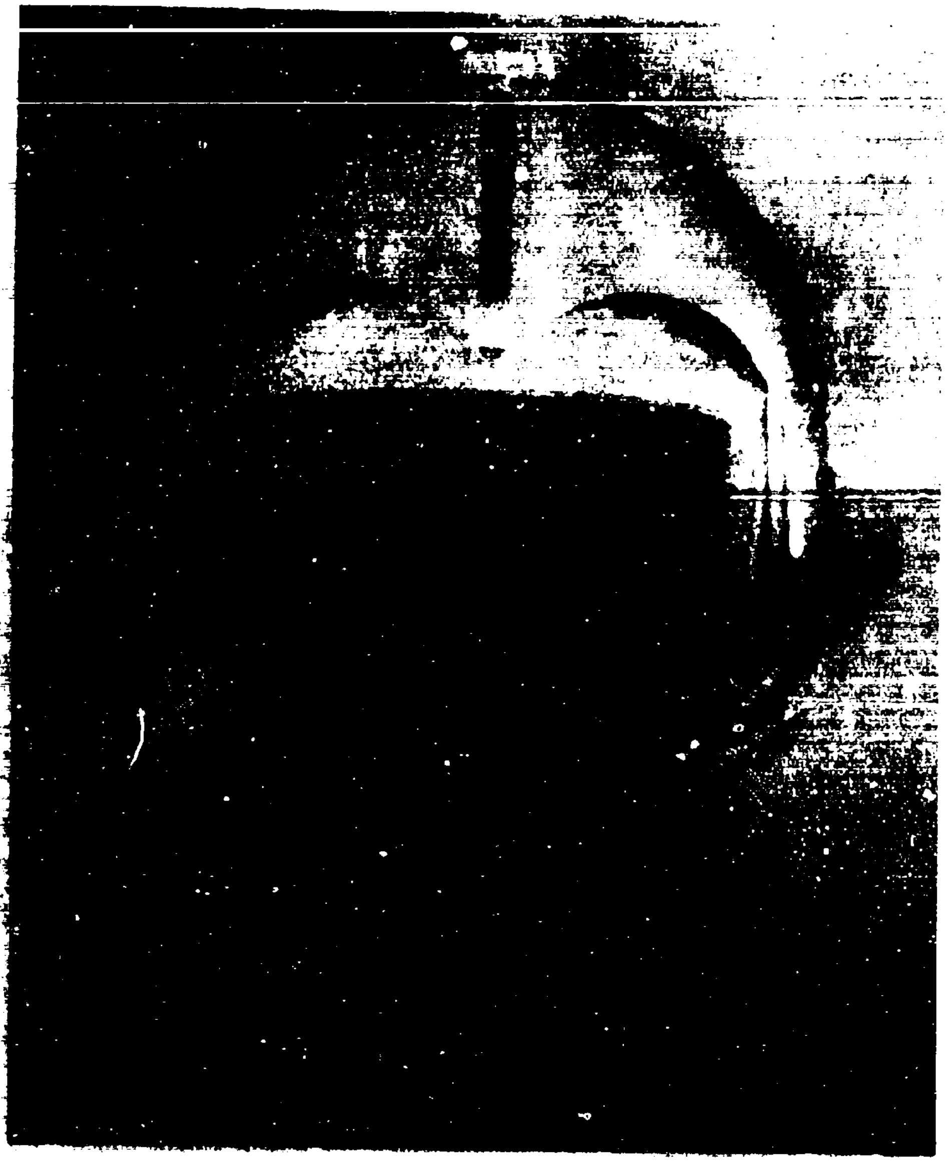

Figure 31. Test Bed HMS/D Arrangement

SECTION IX

HMS/D EFFECTIVENESS MEASURES

BACKGROUND

Under generally recognized methodology, "system effectiveness" is defined as "the quantitative prediction of the extent to which a system may be expected to achieve a set of specific mission requirements under operational conditions, expressed as a function of three major attributes -- availability, dependability, and capability."

The first two attributes refer to organizational maintenance and logistical support of a field system and the on-mission reliability of system components and are probabalistic measures. Normally, "capability" is also taken as a probabalistic measure and can be defined as "the probability of accomplishing the sequential events to the degree defined as a success for each of the possible states of equipment operation."

The measure of capability may include the effects of hostile countermeasures to thwart performance at the defined success level and may also reflect the beneficial aspects of speed, altitude, range, accuracy, timeliness, survivability, etc., on mission performance.

The intent of the HMS/D effectiveness study was to define and compare measures of capability applied to an F-15 type aircraft defining the impact of the HMS/D subsystem on the total weapon system. The generalized nature of the study dictated elimination of a study of availability and dependability measures (as defined earlier) as they are more intimately related to specific hardware specifications.

Among the operating modes of the baseline HMS/D system, the "Search" mode is singular in that it is used solely for pilot display and includes no control functions. The "Search" mode display format is helmet stabilized (fixed to the pilot's head) as is the tracker imagery after sensor lock in the "Identify" mode. All other modes use either sensor or aircraft stabilized display formats. The primary measure of capability in the "Search" mode is the implied improvement in pilot scanning and detection times due to the elimination of the need for the pilot to read the radar display on the instrument panel inside the cockpit. No experiment was conducted to measure the relative times required to detect or identify targets with and without a HMS/D used in these modes. In a single-place aircraft the freedom from the need to look down into the cockpit offers a clear-cut advantage in a combat environment.

Another unique mode of operation is the "Guns" mode. The "Guns" mode utilizes an aircraft-referenced display that translates from the pilot's field of view as he looks away from the fore-aft axis of the aircraft. The information displayed is used by the pilot to maneuver the aircraft into a firing attitude in the same manner as if a traditional head-up display were used. The extreme accuracy required of the head position measuring equipment in order to stabilize the display gives a distinct competitive edge to the head-up display for presentation of gunsight information. However, an automatic or semiautomatic transfer to the "Quick-Radar-Lock" mode may enable the pilot to relock his radar if sufficient time remains in his firing pass. Obviously, the acquisition time in that automatic mode becomes a direct measure of capability. Tracking accuracy is also a direct measure of capability in that for any given sensor or weapon subsystem a certain maximum tracking error is allowable beyond which lock will not occur. Hence, two capability measures may be stated as follows:

- Accuracy (radial error) of pointing a sensor during a tracking time-interval

- Acquisition time from initial detection of a potential target to successful radar or electro-optical tracker lock-on

TRACKING EXPERIMENT DATA

While accuracy and acquisition time are readily identified as useful measures of capability, it can be seen in Volume III of this report, "Tracking Capabilities", that variations exist between individuals as to their tracking and acquisition time characteristics. For this reason, a probabalistic description of accuracy and acquisition time becomes mandatory. The tracking experiment reported in Volume III consisted of 1440 trials (each of approximately 15 seconds) performed by six subjects. Each subject tracked three different target types (static, dynamic, and evasive) using two reticle types for an individual total of 40 trials per reticle/target combination. A total of 480 trials (all subjects and both reticles) were performed on each target type. Since it was shown that there was no significant variation in results due to reticle choice, the total data available (i.e.: 480 trials per target type) can be considered representative of pilot tracking responses. To obtain a probabalistic measure of tracking capabilities it is then only necessary to examine the histograms of frequency of occurrence of errors of a given size and divide by the total number of trials (i.e., 480). It is claimed that the result represents the probability density function of the corresponding variable.

Table V summarizes the detailed results presented in Volume III of this report. It presents the composite mean radial error for all subjects (by target type) over a 15-second tracking interval as well as the standard deviation of each subject's mean error about the composite mean. The table also indicates the average percentage of the 15-second tracking time interval during which a

Table V. Summary of Tracking Experiment Results

Measure	Static Target		Dynamic Target		Evasive Target	
Composite mean radial error	0.68 deg		1.04 deg		1.21 deg	
Standard deviation of subject means about composite mean radial error	0.14		0.31		0.32	
Composite time-on-target after TAT (in seconds and percent of 15 sec)	11.7 sec	78.0%	6.9 sec	45.9%	5.4 sec	36.0%
TOT standard deviation	2.6 sec	17.5%	2.3 sec	15.2%	1.9 sec	12.7%
Composite mean indicated target acquisition time* (TAT)	2.4 sec		2.3 sec		2.2 sec	

*Indicated TAT was 0.8, 0.6, and 0.6 seconds later than actual target acquisition, apparently due to overshoot.

subject was able to keep his LOS within a 2-degree diamond-shape target symbol. Page 19 of Volume III describes the testing procedure in detail.

Table V shows a mean 2.2- to 2.4-second target acquisition time (TAT) indicated by the subjects in the tracking experiment by depression of the acquisition switch. The footnote to Table V notes a 0.6- to 0.8-second delay in the indicated TAT, possibly due to overshooting the target with the reticle and then returning to the target before operating the switch. The delay is illustrated as a function of trial number in Figure 32.

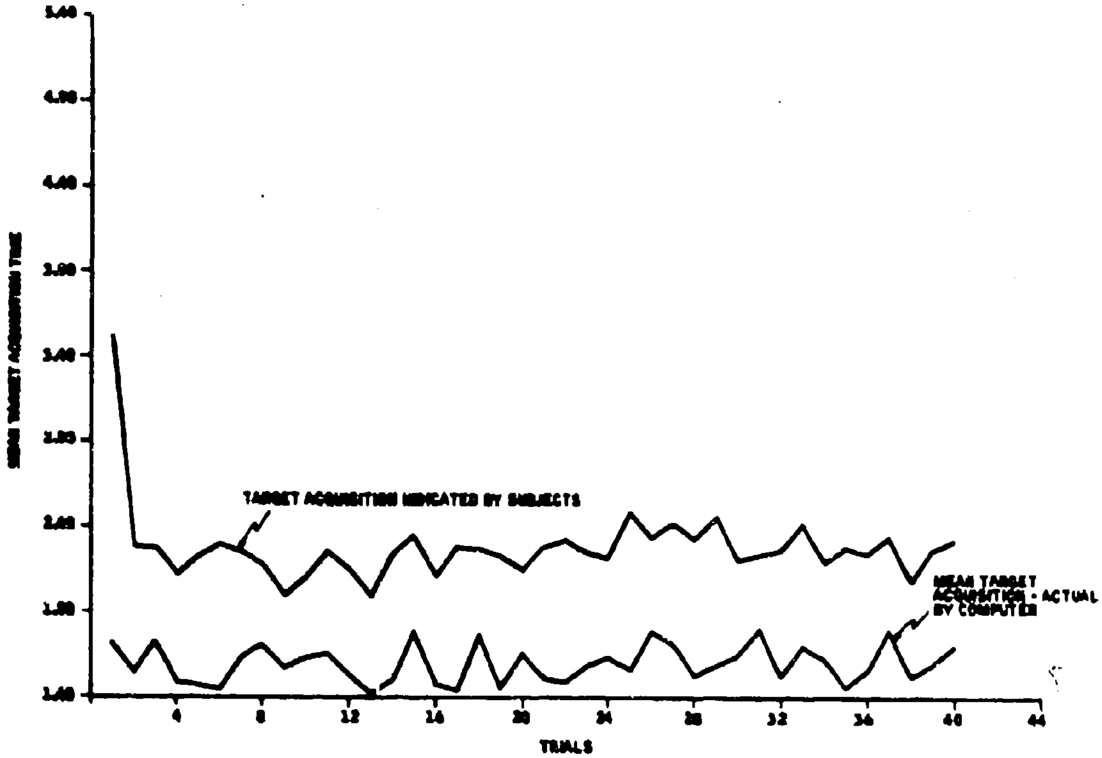

Figure 32. Actual and Indicated Target Acquisition Times

RADIAL TRACKING ERRORS

Figure 33 presents the composite of the six subjects' mean radial error plotted against each of the 40 trials by target type. It should be noted that a given trial refers to a given distinct target path and initial target cue for each target type with the result that, for example, Trial 8 for static targets is unrelated to Trial 8 for either dynamic or predictable path targets. Figures 34 through 36 present composite mean radial errors (all subjects) versus time for specific static, dynamic, and evasive target trials, respectively, for illustration purposes.

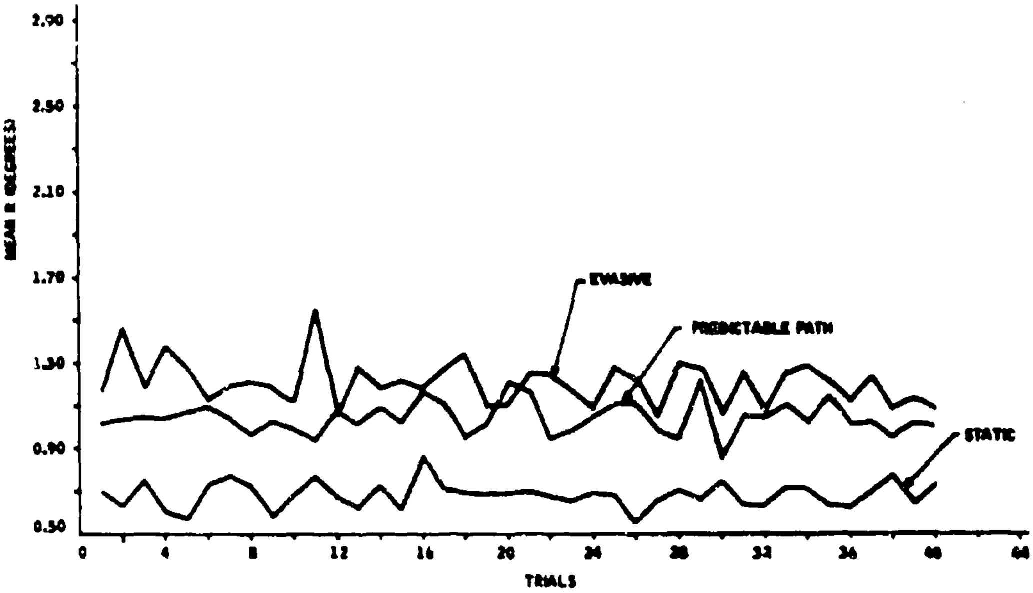

Figure 33. Mean Radial Error for All Subjects by Target Type

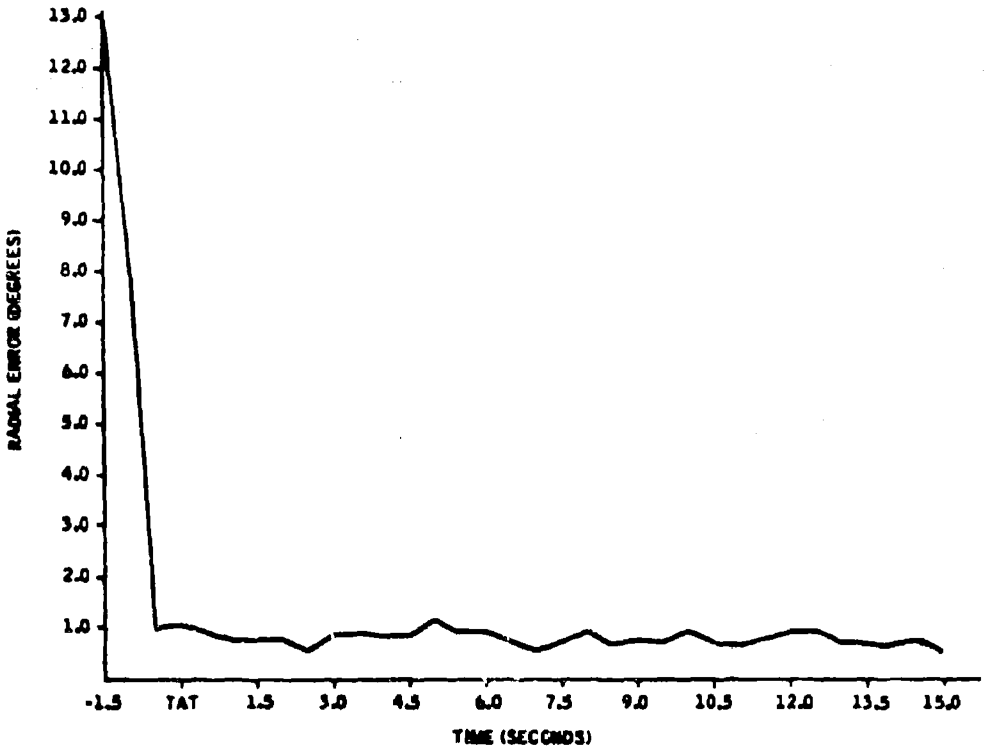

Figure 34. Mean Radial Error for Six Subjects Tracking a Static Target (Static Case 61)

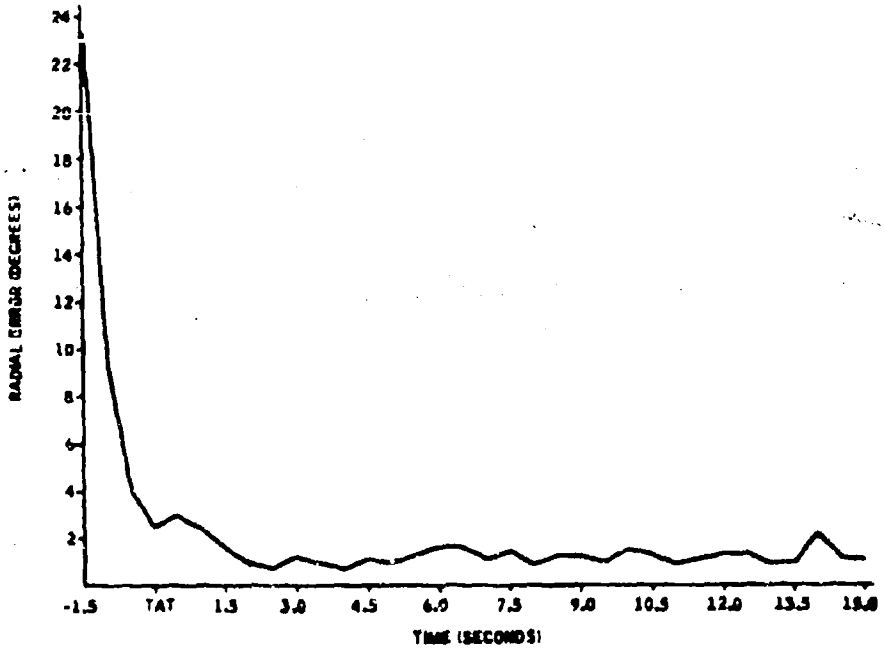

Figure 35. Mean Radial Error for Six Subjects Tracking a Dynamic, Predictable-Path Target (Predictable-Path Case 24)

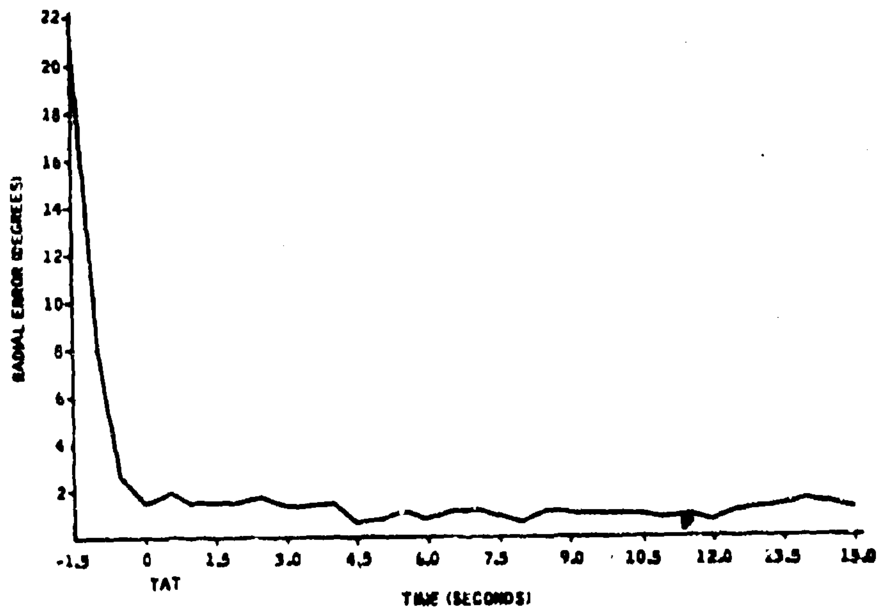

Figure 36. Mean Radial Error for Six Subjects Tracking a Dynamic, Evasive Target (Evasive Case 10)

The data presented in Figure 33 represent, in total, 1440 15-second tracking trials or 480 trials per target type by the group of six subjects. Figures 34 through 36 illustrate the group's time history behavior on a specific target. These data were re-examined to determine a probabilistic measure of tracking accuracy. While the composite mean radial tracking errors shown in Table V may be interpreted to show that a probability of 50 percent exists that a random subject will score a 1.21-degree radial error over a random evasive target trial with a standard deviation of error of 0.32 degree, it was felt that the data reflects nongaussian error characteristics.

As a check, the mean errors of the individual tracking trials were separated into 0.1-degree class intervals and frequency histograms plotted by target type. The frequencies of occurrence were then normalized by division by the number of trials (480) and interpreted as the probability density functions of mean radial error. The integral of the probability density is the probability distribution function and represents the probability than a mean error of a given size or smaller will occur. The results are presented in Figure 37 which depicts the probability of a mean radial tracking error of a given size or smaller versus the mean radial error in degrees. One curve is shown for each target type. A fourth curve, labled "Predictable Path Target - Side Stick," is shown for comparison and will be discussed in the following paragraphs.

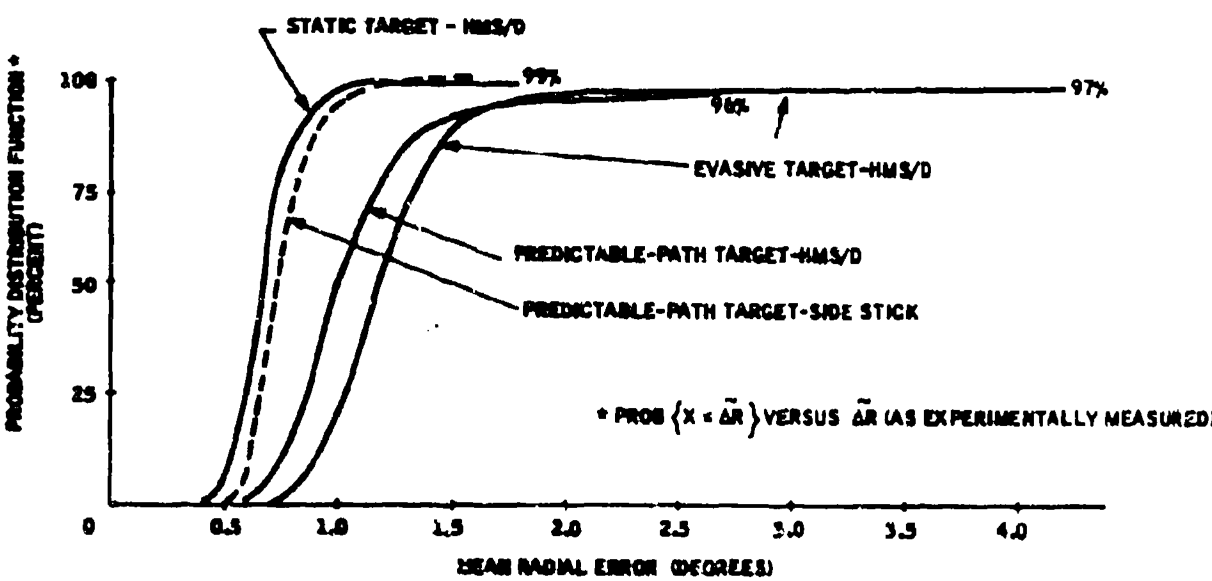

Figure 37. Radial-Error Probability Distribution Functions

SIDE-STICK CONTROLLER EXPERIMENT

A brief experiment using five of the original six subjects was conducted during the effectiveness study in an attempt to infer the tracking characteristics of an operator using a side-stick controller to position a reticle over a moving target on a panel display rather than by head-tracking control of reticle-target relationships on a helmet-mounted display. Forty trials were made by each subject on the same dynamic, predictable-path targets used in the head tracking capability study. The composite mean radial error (i.e., 50 percent probable error) of these 200 trials was 0.76 degree. The error distribution function is shown in Figure 37. As is apparent, the composite mean tracking accuracy results are improved over the head tracking results for the same type of target. Some improvement in accuracy is to be expected as the human tasks in the two experiments differ markedly. The HMS/D coordination task is a compensatory and pursuit task of nulling an error display while the side-stick control task is a pursuit task (i.e., pursuing the target symbol with a reticle symbol). The 25 percent improvement in radial accuracy noted for this experiment is felt to be in line with the variation in task difficulty.

TARGET ACQUISITION AND LOCK-ON

The actual target acquisition times presented in Figure 32 refer to the time required from the start of a tracking trial (i.e., display of a target cueing signal in the field-of-view) to the instant that the subject's LOS entered a 1.5-degree square "box" centered on the target symbol. Indicated target acquisition time began at the same time and ended at the instant when the subject depressed his acquisition switch denoting that he thought he was on-target. The results of the experiment are summarized in Table V and Figure 32 as 1.6 to 1.7 seconds actual and 2.2 to 2.4 seconds indicated (composite mean values).

Depressing the acquisition switch (Indicated TAT) initiated a 15-second tracking trial in the experiment. The "off-angle" from the boresight attitude of the pilot's LOS to the target's initial position varied from 19 to 49 degrees from trial to trial (see p. 17 of Volume III). Note that indicated TAT as used in the experiment referred only to the first instant that the subject thought that he was on target. No quantitative criteria for "on target" were given to the subjects. Actual TAT could occur when the LOS entered the 1.5-degree box only momentarily. Similarly, indicated TAT could occur without the LOS ever entering the 1.5-degree box.

In order to lock a radar or electro-optical contrast tracker to a target successfully, the LOS must enter a given size "window" and remain inside the window for some minimum period of time. For evaluation of sensor locking capability, a minimum "dwell" time duration of 0.3 second was chosen as a compromise value representing a conservatively long lock time for a tracker and time for radar lock at a reasonably short range (on the order of 1 mile).

Arbitrary circular window sizes of 10-, 20-, 30-, and 40-milliradian radius were chosen. Data taken during the tracking experiments defined the times at which each of the windows was first entered for a dwell period of 0.3 second or longer. These data were recorded for all successful tracking trials (i.e., 1404 of the 1440 attempts).

The time data for each target type were sorted and frequency of occurrence in class intervals of 0.1 second were compiled by counting. The resulting histograms are presented as Figures 38 through 40 for static, dynamic, and evasive targets, respectively.

To determine the probability of a stable sensor lock at or before a given elapsed time, the histogram data of Figures 38 through 40 were divided by 480 (the number of tracking trials) and integrated over time. The result is claimed to be the probability distribution functions of stable (i.e., 0.3-second or longer) acquisition within 10-, 20-, 30-, and 40-milliradian radial windows. The results for the three target types are shown in Figure 41. As should be expected, a higher probability is found that the target is within the larger of any two windows at any given elapsed time. For example, at 1 second after TAT there is a probability of 0.9 that either dynamic or evasive targets have been captured (for 0.3 second or longer) within a 40-milliradian window, whereas the probability is approximately 0.5 that during the same time interval a dynamic or evasive target is captured within a 20-milliradian window. The static target window acquisition times are shorter than those for dynamic or evasive targets.

In summary, it should be noted that the total acquisition time capability for different window sizes of the HMS/D is represented by the sum of the mean TAT actual of Table V (i.e., 1.6 to 1.7 seconds) and the time after TAT displayed in Figures 38 through 41. To use the previous example, a probability of 0.5 exists that a target (dynamic or evasive) will be captured within a 20-milliradian window within 1.6 seconds acquisition time plus 1.0 second search and dwell time or 2.6 seconds total after the pilot is cued that a target exists. The above statement says that it is 0.5 probable that a pilot can lock a missile sensor or relock a broken radar lock at short range within 2.6 to 2.9 seconds after detection of the presence of a target or indication of a broken lock.

NAVIGATION UPDATE

The basic measure of navigation update capability is an estimate of the resultant downrange and crossrange position error induced by LOS errors in the triangulation of ground position coordinates.

While analytical studies have been made of the transfer function between sighting accuracy and CEP of ground coordinates, these studies are of no more than passing interest since several actual flight tests involving an instrumented

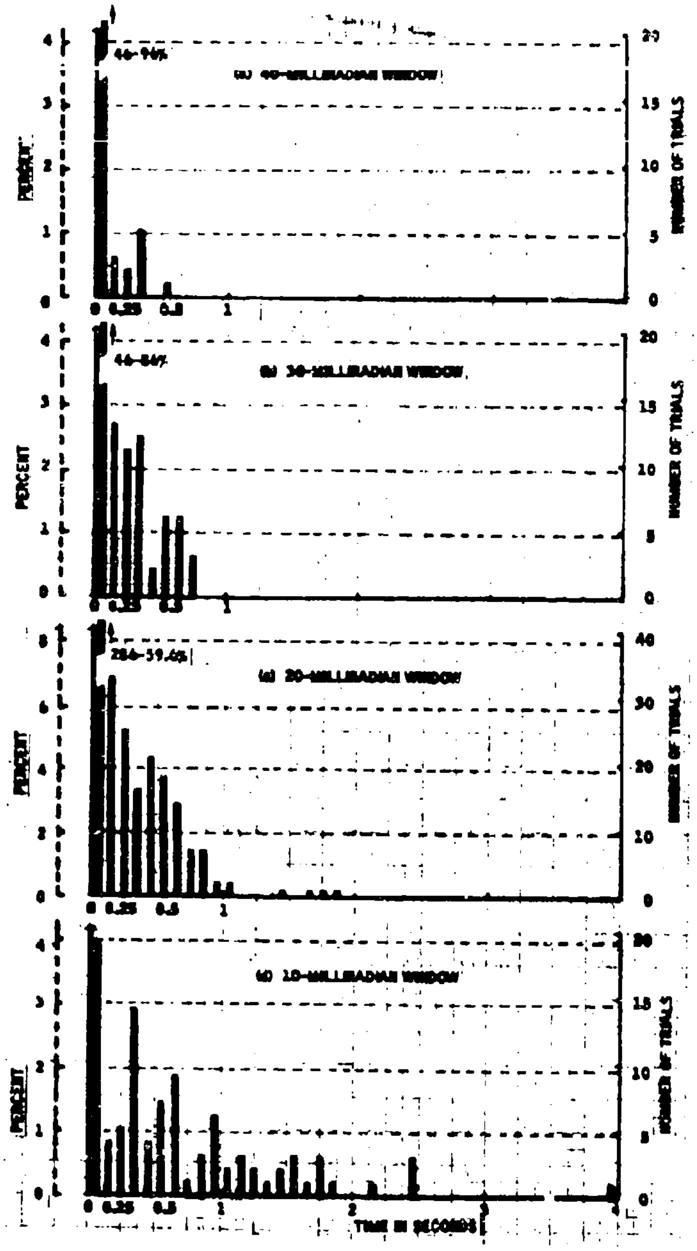

Figure 38. Histograms of Window Entry for 0.3 second or Longer - Static Targets

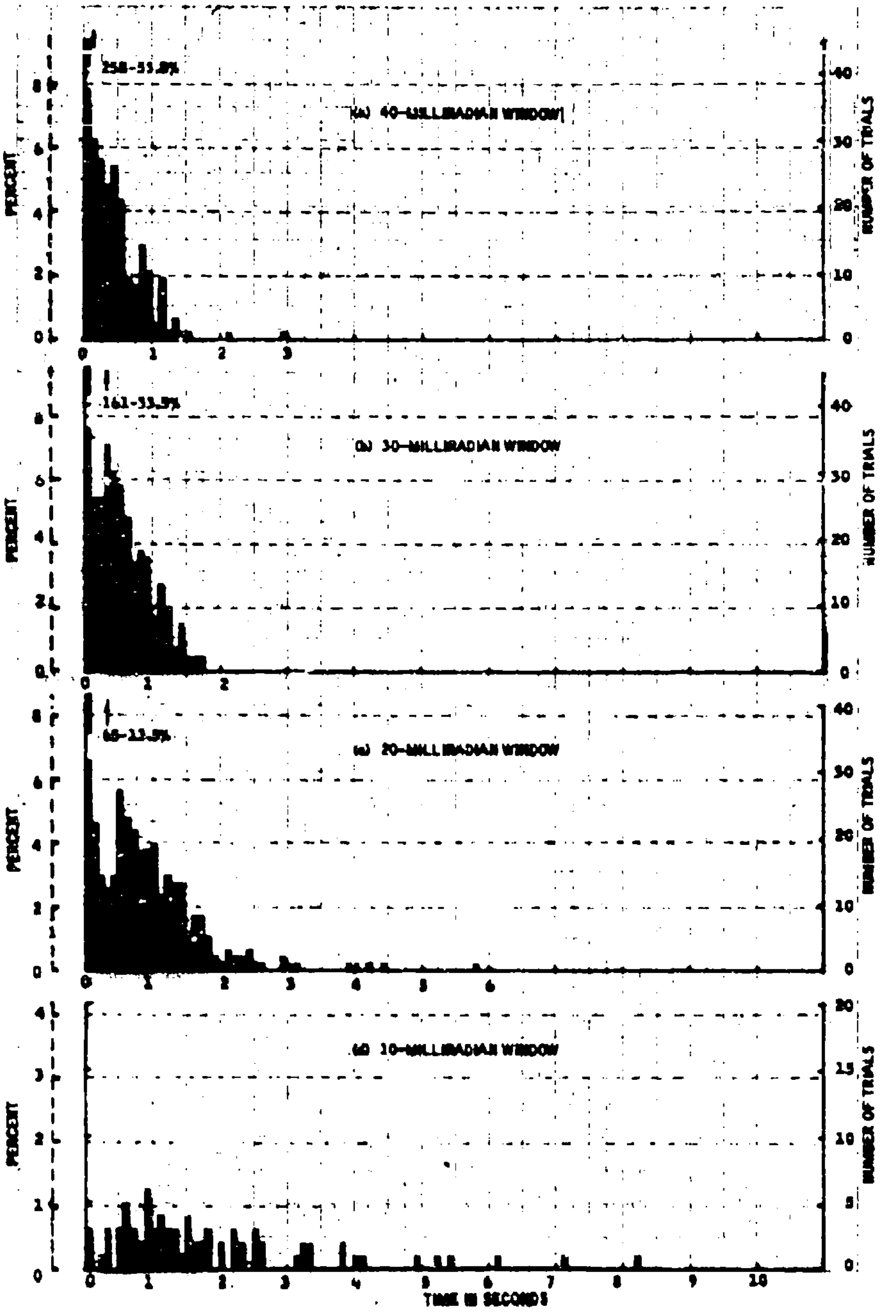

Figure 39. Histograms of Window Entry for 0.3 second or Longer - Dynamic Targets

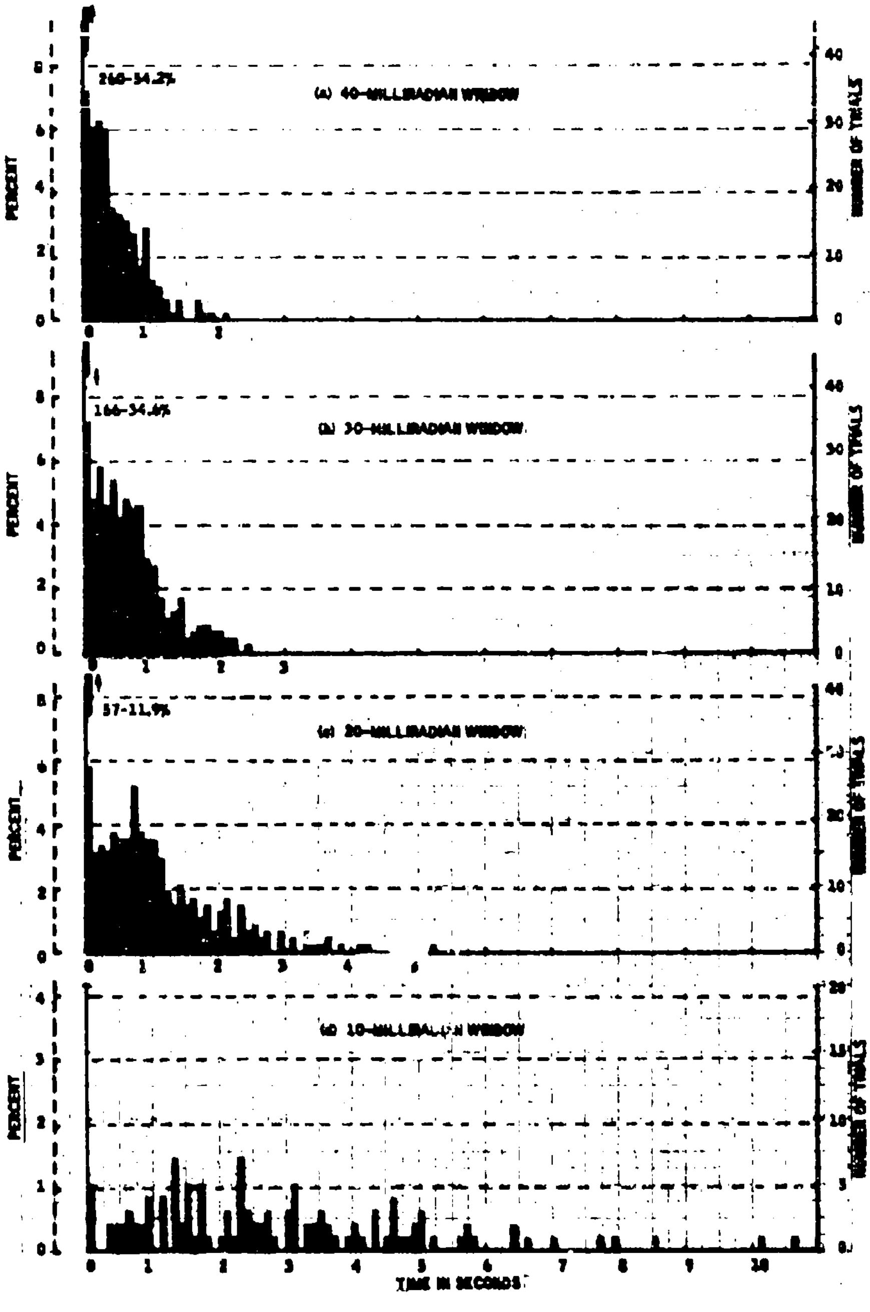

Figure 40. Histograms of Window Entry for 0.3 second or Longer - Evasive Targets

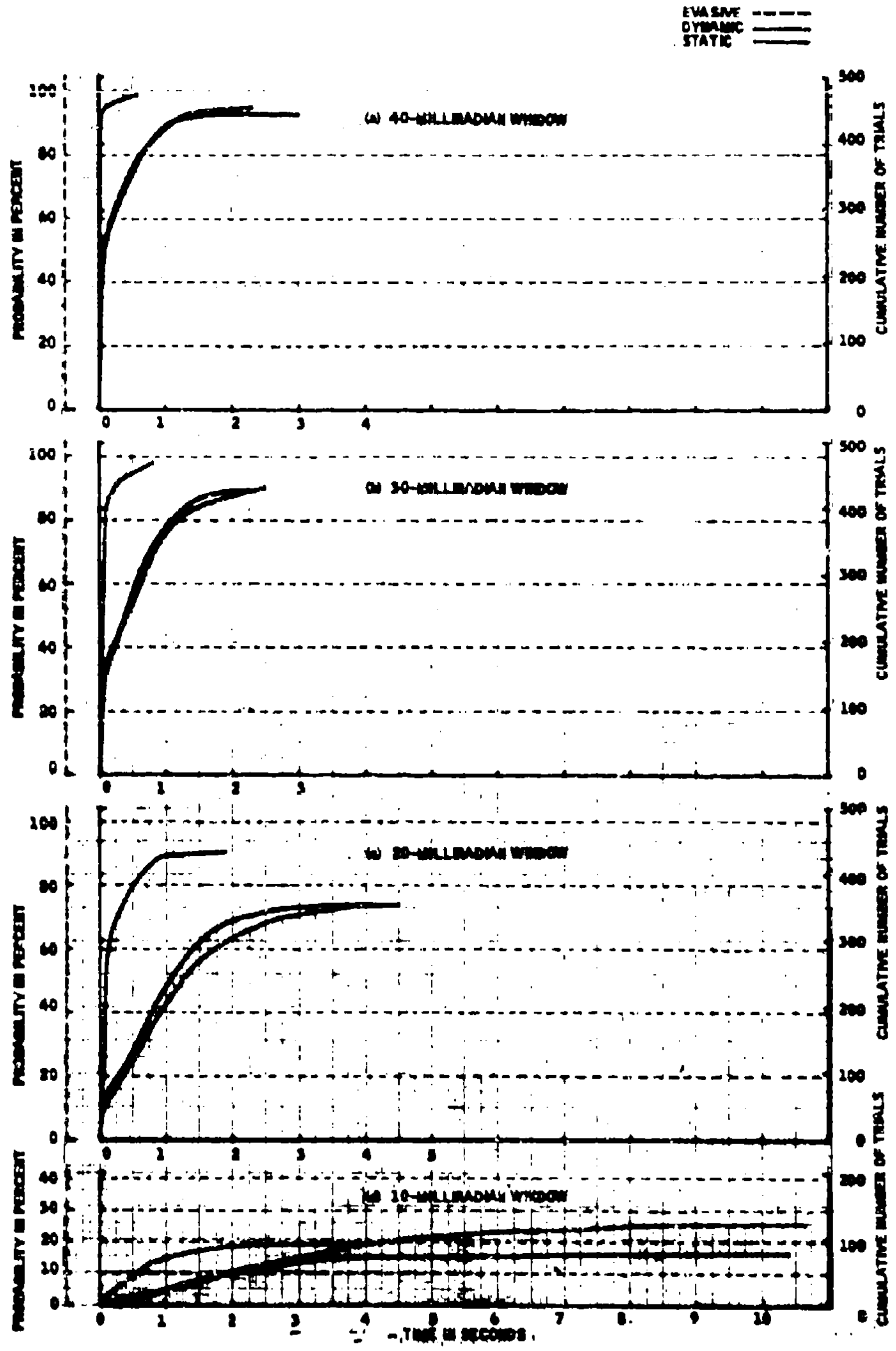

Figure 41. Probability Distribution Functions for 0.3-second or Longer Window Acquisition

RF-4C TACREACT aircraft have been conducted. The official flight test report is in the process of publication as Tactical Air Reconnaissance Center TARC TAC Test Report 67-118, TACREACT, 1969, and is classified Secret.

A Honeywell Report ASD-TR-68-66 entitled "Tactical Reaction Reconnaissance System Studies (TACREACT) (U) - Volume II, Part 1: Visual System Design Breadboard Flight Demonstration System", March 1969, documents the analyses, flight simulator tests, and preliminary flight test data referred to in the above paragraph.

The Honeywell report and data concerning NAV-UPDATE accuracies is also classified Secret. In order to avoid use of Secret data, this report will simply refer to the TARC report as representative of what is probably the best measure of system effectiveness, i.e., flight test performance.

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1. Project ADC/AFSC/ADWC 67-11; Air-to-Air Recognition System (ATAR); Final Report; Aerospace Defense Command; Ent AFB, Colorado; 2 August 1968.

2. USAF; TARC; TACREACT; TAC Test No. 67-118; TAC Identifier 7058-010504; January 1968; Tactical Air Command; USAF Tactical Air Reconnaissance Center; Shaw AFB, S. C.; (To Be Published).

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13. ABSTRACT

This report describes the system studies and experimental work done to determine the applicability of a helmet-mounted sight/display (HMS/D) to high-performance aircraft of the F-15 type. The HMS/D was found to have several areas of applicability to such aircraft, particularly in the mission phases having to do with weapon delivery. Closed-loop performance of the sight/display combination was examined experimentally as a part of the study. The performance experiment is based on the ability of the engineer subjects to sight and track targets displayed on the helmet display. Interface of the HMS/D with other aircraft systems was considered, and a baseline HMS/D system was defined to the degree necessary to enter a prototype development phase.

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System studies						
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Applicability						
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High-performance aircraft						
F-15 type						
mission phases						
weapon delivery						
Closed-loop performance						
Sight and track targets display on helmet display						
Baseline HMS/D system defined for prototype development phase						

Unclassified

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